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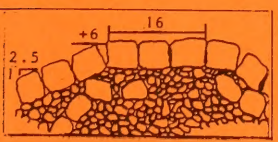

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TECHNICAL REPORT REMR-CO-3

CASE HISTORIES OF CORPS BREAKWATER AND JETTY STRUCTURES

Report 9
SOUTHWESTERN DIVISION

by

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GT	Geotechnical	EI	Environmental Impacts
HY	Hydraulics	OM	Operations Management
CO	Coastal		

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COVER PHOTOS:

TOP — Field Research Facility, Duck, North Carolina.

BOTTOM — Cross-sections depicting cavity in jetty, section of jetty after release of cover stone, and repaired section, Brazos Island Jetties, Brazos Island Harbor, Texas.

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This report is ninth in a series of case histories of US Army Corps of Engineers (Corps) breakwater and jetty structures at nine Corps divisions. Herein, case histories are presented for 12 breakwater and jetty structures located within the US Army Engineer Division, Southwestern (SWD), along the Texas gulf coast. Presently, there are 4 breakwaters and 19 jetties managed by SWD with a cumulative length of over 176,000 ft. These structures are predominantly of rubble-mound construction. Concrete caps have been used on the projects, but since 1960 a fairly consistent cross section of stone only has been used on new and existing projects. The peak period of construction occurred from 1962 to 1966 when three projects were completed and six received major rehabilitations. Although wave forces may be the principal cause of structure deterioration, scour and undermining also appear to be significant.

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PREFACE

This report was prepared as part of the Coastal Problem Area of the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program. The work was carried out jointly under Work Unit 32278, "Rehabilitation of Rubble-Mound Structure Toes," of the REMR Program and Work Unit 31269, "Stability of Breakwaters," of the Civil Works Coastal Area Program. For the REMR Program, Coastal Problem Area Monitor is Mr. John H. Lockhart, Jr., Office, Chief of Engineers (OCE), US Army Corps of Engineers (Corps). REMR Program Manager is Mr. William F. McCleese of the US Army Engineer Waterways Experiment Station's (WES's) Structures Laboratory, and Coastal Problem Area Leader is Mr. D. D. Davidson of WES's Coastal Engineering Research Center (CERC). Messrs. John G. Housley and Lockhart, OCE, are Technical Monitors of the Civil Works Coastal Area Program.

This report is ninth in a series of case histories of Corps breakwater and jetty structures at nine Corps divisions. The case histories contained herein were extracted from information obtained from several sources (where available) which included inspection reports, conferences, telephone conversations, project plans and specifications, project files and correspondence, design memorandums, literature reviews, model studies, surveys (bathymetric and topographic), survey reports, annual reports to the Chief of Engineers, House and Senate documents, and general and aerial photography. Unless otherwise noted, only prominent changes to the prototype structures subsequent to March 1986 are included in this report.

This work was conducted at WES during the period July to October 1986 under general direction of Dr. James R. Houston, Chief, CERC, and Mr. Charles C. Calhoun, Jr., Assistant Chief, CERC; and under direct supervision of Mr. C. Eugene Chatham, Jr., Chief, Wave Dynamics Division (CW), and Mr. D. D. Davidson, Chief, Wave Research Branch (CW-R), CW. This report was prepared by Messrs. Francis E. Sargent and Robert R. Bottin, Jr., CW. This report was typed by Ms. Myra Willis, CW, and edited by Ms. Shirley A. J. Hanshaw, Information Products Division, Information Technology Laboratory, WES.

COL Dwayne G. Lee, EN, was Commander and Director of WES during the publication of this report. Dr. Robert W. Whalin was Technical Director.

CONTENTS

	Page
PREFACE	1
CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT	3
PART I: INTRODUCTION	4
Background	4
Purpose	4
PART II: SUMMARY OF CORPS BREAKWATER AND JETTY STRUCTURES IN SWD	6
REFERENCES	53

CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic yards	0.7645549	metres
feet	0.3048	metres
inches	2.54	centimetres
miles (US statute)	1.609344	kilometres
pounds (force)	4.448222	newtons
pounds (force) per square foot	47.88026	pascals
square feet	0.09290304	square metres
tons (2,000 lb force)	8806.443353	newtons
square yards	0.83612736	cubic metres

CASE HISTORIES OF CORPS BREAKWATER AND JETTY STRUCTURES SOUTHWESTERN DIVISION

PART I: INTRODUCTION

Background

1. The US Army Corps of Engineers Corps is responsible for a wide variety of coastal structures located on the Atlantic, Pacific, and gulf coasts, the Great Lakes, the Hawaiian Islands, other islands, and inland waterways. Coastal improvements such as breakwaters or jetties are necessary to provide harbor protection and safe passage of vessels. These structures are subjected continuously to wave and current forces and usually are constructed on top of movable-bed materials. Under these conditions structural deterioration can occur and, at some point, maintenance, repair, or rehabilitation is required if the structure deteriorates and/or fails to serve the existing needs of the project. Some of these projects have been maintained for 150 years or more. Methods of construction and repair have varied significantly during this time, due principally to a better understanding of coastal processes, availability of construction materials, existing wave climates, regional construction practices, and economic considerations.

Purpose

2. The purposes of this report are to provide insight into the scope, magnitude, and history of coastal breakwaters and jetties under Corps jurisdiction; to determine their maintenance and repair history; to determine their methods of construction; and to make this information available to Corps personnel. To accomplish these objectives, case histories of Corps breakwater and jetty structures have been developed to quantify past and present problem areas (if any), take steps to rectify these problems, and to subsequently evaluate the remedial measures. General design guidance can be obtained from the solutions that have been most successful. Information in this report should be of particular value to Corps personnel in the US Army Engineer Division, Southwestern (SWD), and its coastal districts and possibly to non-Corps personnel. Further research is being conducted to

address problems where adequate solutions are lacking or where specific guidance is required (i.e., general armor stability, toe protection, localized damage, use of dissimilar armor, wave runup, and overtopping.

PART II: SUMMARY OF CORPS BREAKWATER AND JETTY STRUCTURES IN SWD

3. The SWD presently maintains 12 coastal projects which contain a total of 4 breakwaters and 19 jetties. These projects are located within US Army Engineer District, Galveston (SWG), which includes the entire Texas gulf coast (Figure 1). The eight projects located directly on the gulf and the Port O'Connor project contain dual jetties; the Palacios and Port Aransas Harbor projects contain dual breakwaters; and the Point Bolivar project has a single jetty.

4. Cumulative length of the structures is 176,333 lin ft*, of which the Galveston Harbor and Sabine Pass jetties account for 61.4 percent and the two breakwater projects account for 2.4 percent. As originally constructed, about 170,177 lin ft (96.5 percent) had a rubble-mound cross section and the remainder--6,165 lin ft at point Bolivar and Port O'Connor--had essentially a steel-sheet-pile structure. Approximately 3,230 lin ft of sheetpiling has since been supplemented with a rubble-mound section, and nearly 62,900 lin ft of the structures have been capped with asphalt or concrete although the present amount is somewhat less due to subsequent alterations. The asphalt capping, totaling 3,944 lin ft, was placed at four sections of the Galveston Harbor jetties during the 1930's.

5. The five projects at Sabine Pass, Galveston, Freeport, Aransas Pass, and Brazos Island have a history predating 1900. These early projects were marked by various construction methods and extended time periods resulting from several factors, including availability of materials, inadequate design guidance, storm damage, economics, and the construction methods themselves. Fascine mats ballasted with riprap stone were the prevalent early method of construction. This type of construction was used at Sabine Pass into the 1920's but was discontinued on the remaining projects prior to 1900. The resulting construction method consisted of building a rubble-mound section directly on existing ground, starting with small riprap stone, building up the section with a core of various sized riprap stone (laterally confined by prior placement of larger cover slope stone), and covering with granite pieces weighing several tons each. The project at Brazos Island was finally realized

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

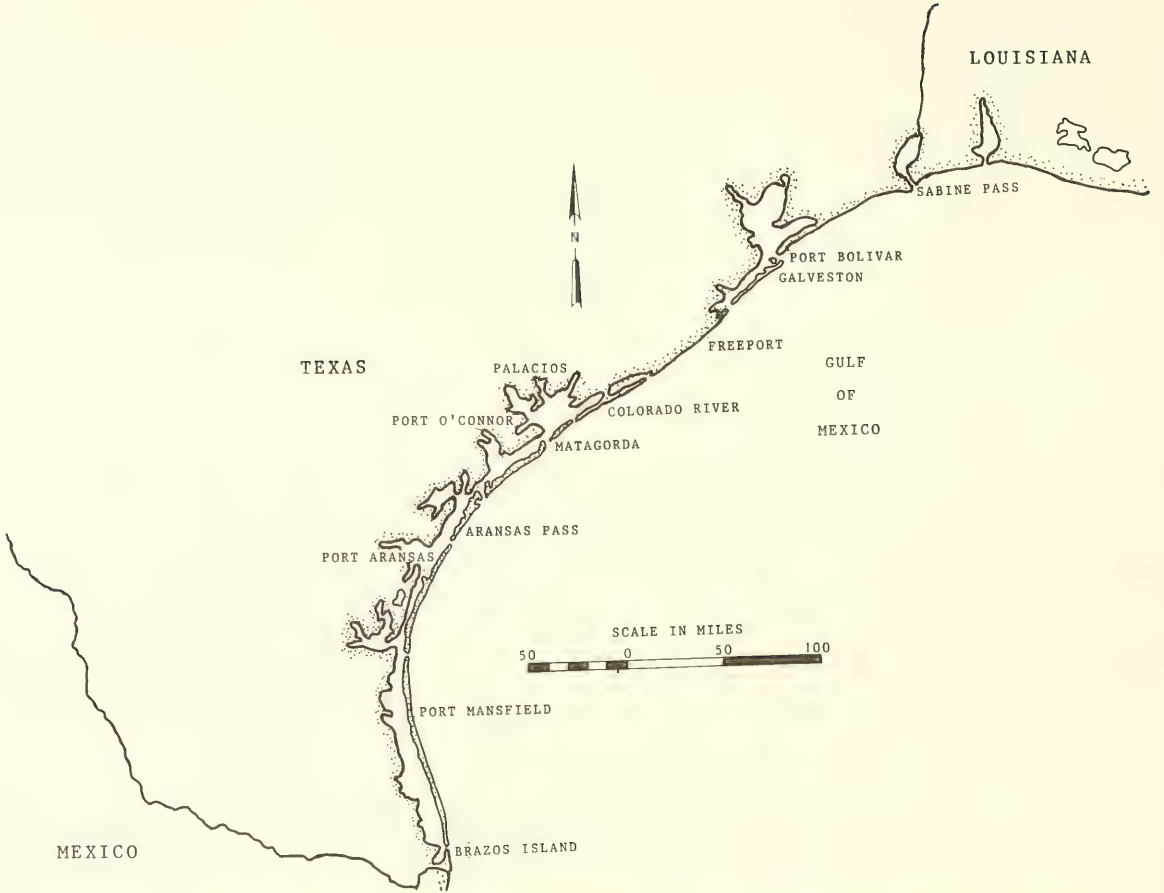

Figure 1. Location of projects within SWD which contain breakwater or jetty structures

with the construction of rubble-mound jetties in the 1930's. Also completed during the 1930's were the steel sheet-pile structures (dikes) located on the Gulf Intracoastal Waterway at Port Bolivar and Port O'Connor.

6. Concrete capping was first used in the early 1900's at Sabine Pass, Galveston, and Freeport but in each case was limited to placement toward the landward end of a single jetty. During the 1930's and early 1940's additional concrete capping was used on both jetties at each of these projects. The Aransas Pass jetties were capped with concrete, and asphalt capping was placed on the Galveston jetties. These caps were rectangular or trapezoidal in cross section and were placed on top of the existing armor stone which itself was repaired or chinked with stone prior to capping. In the 1950's concrete was placed at the Brazos Island and Aransas Pass jetties. These sections varied from the previous caps in that the concrete was integrated directly into the cover stone layer, forming a homogenous section of concrete and armor stone.

7. The period from 1962 to 1966 marks the era of maximum construction of new and existing breakwater and jetty structures. Constructed at this time were the breakwaters at Palacios and the jetties at Matagorda and Port Mansfield. Major portions of the jetties at Sabine Pass, Point Bolivar, Galveston, Port O'Connor, Aransas Pass, and Brazos Island were rehabilitated; and the Freeport jetties received minor repairs. Subsequent efforts include the construction of breakwaters at Port Aransas in 1973, the Colorado River jetties (which include a rubble-mound weir section) completed in 1986, and rehabilitation of the Brazos Island north jetty during the 1970's.

8. Cross-section geometry and structure composition have been fairly consistent since at least 1962. Crown elevations vary between +4 and +8 ft mean low tide (mlt), and crown widths range from 8 to 20 ft. Side slopes are typically from 1V:1.5H to 1V:3H on trunk sections and 1V:2H to 1V:4H on head sections. Various sizes of granite stone are used in the section, beginning with a bedding layer of 0.5-in. to 200-lb stone and varying from 2 to 5 ft in thickness. This bedding layer has, in turn, acted as an apron by extending it, typically 5 to 50 ft beyond the cover layer toe. Recently, toe protection stone has been used in place of the extended bedding layer. Equal in size to the core stone, it buttresses both the bedding and cover layers. The core stone typically varies from 200 to 1,000 lb (but can be up to 4,000 lb on head sections) and, to decrease permeability, is supplemented with 0.5- to 4-in. filler stone. The geometry of the combined core and filler stone extends

outward beneath the full crown width at 1V:1H side slopes. The cover layer stone size varies from 2 to 18 tons (although a particular structure may have used just a portion of this range), increasing in 2-ton size increments along successive seaward sections. The cover stone has a unique shape which resembles a rough surfaced, slightly flattened cube. The cover stone are placed in a single layer, except on head sections where a double layer is used on the side slopes. Typically, the cover layer toe is buttressed with an additional 1 to 3 stones of equal size placed horizontally atop the bedding layer.

9. Except for various caps used on the structures, all repairs have consisted of placing additional stone. The frequency of repairs was highest prior to World War II, although the Aransas pass and Brazos Island jetties have been repaired at about the same frequency to the present. The general trend of the repairs has been toward the use of larger stone placed on shallower side slopes. Also, the use of concrete on the jetties as a repair method has been discontinued. The caps have met with mixed success. The crown has remained reasonably intact, while the underlying stones have subsided, causing void spaces and eventual collapse of the unsupported cap. Repairs to previously capped sections have been made by adding buttressing and slope stone or breaking up the cap and adding stone. Several of the recent repair efforts have concentrated on one side of the structure using the existing section as a buttress. Repairs at the structures' seaward ends typically have consisted of rebuilding the head landward of the original seaward end. The Port O'Connor and Port Bolivar steel structures were repaired along seaward sections by the addition of rubble-mound cross sections and have not been repaired since.

10. While many of the repairs were necessitated by wave-induced damage, perhaps of equal importance has been the scour and undermining at the base of the structures caused by current- and wave-induced bottom stresses. The jetties at Sabine Pass underwent large amounts of settlement during their lengthy period of construction. Scour appears to have been a contributing factor of deterioration on the jetties at Aransas Pass, Brazos Island, Port Mansfield, Matagorda (during construction), Port O'Connor (prior to rehabilitation), the Galveston north jetty, and the Freeport south jetty. Apron stone was added to the Brazos Island jetties within a few years of construction. Spurs were placed on the Aransas Pass jetties in 1923, 1956, and 1965. The present conditions of the structures are considered good to excellent with the exception

of the Freeport jetties which have received only minor repairs since the 1940's. The possibility of project modifications at Freeport has delayed jetty rehabilitation.

11. Design of the structures during the past 25 years is based on various engineering memorandums and Coastal Engineering Research Center (CERC) publications, in addition to the experience gained from construction and maintenance of the existing structures. Selection of armor stone size and slope is based on Hudson's slope stability formula. For the gulf coast wave climate, stability coefficients used in designs typically are above zero damage levels, resulting in a nonconservative design at the structures' seaward ends but considered adequate in light of past experience and additional costs required for a fully stable design. Design wave heights and maximum surge levels are typically determined from historical hurricane events, observed wind and tide data, and an expected 50- to 100-year storm recurrence interval. Design wave heights are depth-limited in regions where they exceed 0.78 times the water depth. Actual wave data were not used in any design, and it is not known whether any useful data exist. Although no model studies have been conducted on stability of structure cross sections, prototype data were collected and analyzed for Port Mansfield (Kieslich 1977), and functional hydraulic model studies were conducted for Galveston (Simmons and Boland 1969) and Matagorda (Rhodes and Simmons 1966).

12. Case histories of the structures for each project are included in Tables 1-12. Pertinent summary information on each project is presented in the following listing.

Location	Table	Project Type and No.*	Armor Type**	Length, ft	Date of Origin	Improvement†
Sabine Pass	1	J(2)	S,P	47,130	1883	R
Port Bolivar	2	J	S	1,900	1933	R
Galveston	3	J(2)	S,P	61,200	1874	R
Freeport	4	J(2)	S,P	9,726	1881	R
Colorado River	5	J(2)	S	4,100	1984	N
Palacios	6	B(2)	S	2,030	1966	N
Port O'Connor	7	J(2)	S	4,550	1939	R
Matagorda	8	J(2)	S	11,900	1963	R
Aransas Pass	9	J(2)	S,P	16,625	1880	R
Port Aransas	10	B(2)	S	2,140	1973	N
Port Mansfield	11	J(2)	S	4,570	1957	R
Brazos Island	12	J(2)	S,P	10,462	1933	R

* Indicates type and number of structure: J-jetty, B-breakwater (B(2) indicates two breakwaters).
** Indicates armor type: S-stone armor, P-concrete cap.
† R- repair, N-none.

Table 1

Sabine Pass Jetties

Sabine-Neches Waterway, Texas

Date(s)	Construction and Rehabilitation History
1883-1900	Two jetties were constructed using multiple layers of fascine mattress and stone ballast. Typical mattress widths varied from a minimum of 15 ft on the uppermost layer to maximums of 60 to 120 ft on the lowermost (foundation) layer. Both jetties were extended several times reaching total lengths of 25,000 and 22,000 ft for the foundation course of the east and west jetties, respectively. The jetties were subsequently raised to about +2 ft mean high water (mhw) by addition of riprap stone and a cover layer of granite blocks. Individual cover stones were probably several tons in size (the 1891 contract required 1- to 4-ton stone). By 1900 raised sections of the east and west jetties totaled 21,820 and 15,560 ft in length, respectively. Subsidence of the jetties was significant, caused by a combination of scour and consolidation of the underlying soil and consolidation and deterioration of the fascine mats. Portions of the jetties (usually at their outer ends) were damaged or destroyed during passing storms, resulting in repair or reconstruction of these sections. Approximately 8,000,000 sq yd of fascine mats and 776,000 tons of stone were used in jetty construction for a total cost of $2,541,900.
1904-1909	The east jetty was repaired and raised with additional riprap stone. About 19,800 ft of its length was built up to +4 ft mlt. A total of 206,750 tons of stone was placed at a total cost of $514,500.
1910-1911	The west jetty was capped with concrete from its landward end (at sta 0+00) to sta 157+80, and 1910 granite blocks were transferred from the west jetty to the east jetty. A total of 60,000 tons of stone and 11,580 cu yd of concrete was placed on the west jetty. Total cost was $275,000.
1912-1913	The east jetty was repaired from sta 53+00 to sta 138+50 using 48,200 tons of stone, and west jetty repairs from sta 80+00 to sta 157+50 required 20,400 tons of stone. Total repair cost was $238,700.
1914-1918	The east jetty was extended and raised using 16,750 sq yd of fascine mats and 293,400 tons of stone. The jetty had been raised to +5 ft mean low gulf (mlg) from sta 0+00 to sta 243+00. In 1916 repairs were made to the west jetty using 21,700 tons of stone. About 15,900 ft of the west jetty was at +4 ft mlg, and 2,200 ft at its seaward end was at -4 ft mlg. Total cost of the extension and jetty repairs was $1,152,100.

(Continued)

Table 1 (Concluded)

Date(s)	Construction and Rehabilitation History
1920	The east jetty was completed to its project length of 25,270 ft and an elevation of +5 ft mlg using 44,370 tons of stone.
1924-1928	The west jetty was raised and extended to its project length of 21,860 ft and elevation of +4 ft mlg. A total of 27,860 sq yd of mattress and 178,700 tons of stone was placed. The approximate total cost for jetty completion was $860,000. As constructed, the jetties are slightly converging to an opening 1,800 ft wide at their seaward ends (Figure 2).
1930-1934	Repairs were made to the jetties by adding stone and resetting existing cover stone. The 5,400 reset stones were to weigh a minimum of 2 tons each. A total of 67,700 and 26,100 tons of stone was placed on the east and west jetties, respectively. The east jetty repairs were carried out between sta 129+15 and sta 240+95. Costs and locations of west jetty repairs are unknown.
1936-1941	The jetties were capped with concrete. The east jetty cap, placed from sta 183+67 to sta 253+10, had an elevation of 5.7 ft mlt and a top width of 10 ft. The west jetty cap was placed on the existing cap to an elevation of +4 ft mlt and an overall width of 10 ft. Stone totaling 23,130 tons and 15,070 cu yd of concrete were placed at a total cost of $608,000.
1957-1958	The west jetty was repaired using 60,200 tons of stone at a cost of $834,800 (location of repairs unknown). Cover stone weighed 9 to 13 tons each, and core stone weighed 25 to 200 lb each.
1960-1966	Repairs were made from sta 60+00 to sta 183+67 and sta 68+00 to sta 179+50 on the east and west jetties, respectively (Figure 2). The east jetty was brought up to +7 ft mlt with a 9-ft crown width and 1V:1.5H side slopes. A similar cross section was used on the west jetty from sta 68+00 to sta 90+75 with the cover layer placed over the concrete cap. The remainder of the west jetty cap section was raised with core stone to +1 ft mlt, 1V:1.5H side slopes and covered with armor stone. The core stone varied from 25 to 200 lb. The cover stone varied from 4 to 13 tons between the landward and seaward ends of the repairs, respectively. A total of 430,000 tons (approximate) of stone was placed at a total cost of $3,961,000.
1986	No work has been done on the jetties since the 1960's, and they are considered to be in good condition, except for a 6,000-ft section at the west jetty's shoreward end.

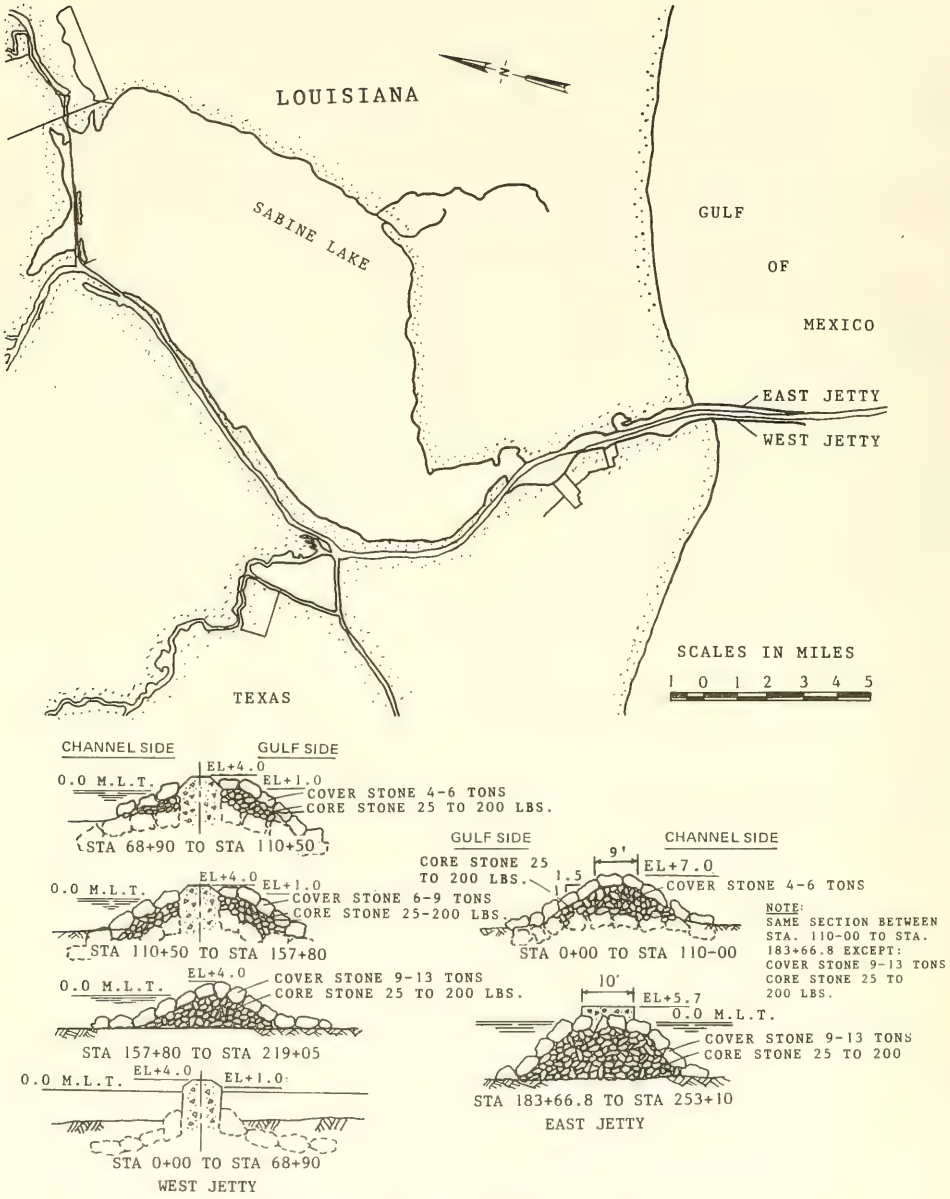

Figure 2. Location map and typical cross sections of Sabine Pass jetties

Table 2

Port Bolivar Dike

Port Bolivar, Texas

Date(s)	Construction and Rehabilitation History
1933-1934	A 1,700-ft-long steel sheet-pile dike was constructed to prevent shoaling in the Gulf Intracoastal Waterway at this location (Figure 3). The seaward end of the dike consisted of a 12-ft-diam sheet-pile cell, with a 2-ft-thick concrete cap (and underlying fill material), protected by a stone blanket at the toe of the cell. The top elevation of the sheet pile was +4 ft mlt. Existing water depths varied from -4 (landward) to -13 (seaward) ft mlt. A total of 47,500 sq ft of sheet pile and 6,670 tons of stone was used. Cost of the improvements was $25,000.
1936-1937	The landward end of the dike was repaired and extended 200 ft at a cost of $7,050. Approximately 230 tons of stone was placed as scour protection at the seaward end at a cost of $1,750.
1966	The outer 1,230 lin ft of sheet pile was supplemented with a rubble-mound section similar to the 1964-1965 Port O'Connor repairs. The dike was generally intact, with some damage to the piling at the outer end and a heavy coating of rust scale due to saltwater exposure. Existing ground elevations varied from -5 ft mlt near the seaward end to +4 ft mlt along the unrepaired landward segment (in general, an accretion of 6 to 8 ft had occurred since original construction). The outer sheet-pile cell, with a maximum water depth of -11 ft mlt, was the only section where localized scour was evident (but in this case not critical to structural integrity). The sheet-pile top elevation was generally from +3.5 to +4 ft mlt (within 0.5 ft of the design elevation). The rubble-mound design sections (Figure 3, inset), with the existing dike at the center line, had a crown elevation varying from +4 (seaward) to +6 (landward) ft mlt, a crown width of approximately 8 ft (2 cover stones wide) and 1V:2H side slopes. The sections were built upon a 2-ft-thick (3 ft at outer end) bedding layer of 0.5-in. to 200-lb stone. The bedding layer extended from 3 ft (landward) to 10 ft (seaward) beyond the toe of the cover layer and was covered with a 2-ft-thick layer of 200- to 1,000-lb apron stone. Similar sized stone were used as core stone, and the outer layer consisted of 1- to 6-ton stone. Filler stone (0.5 to 4 in.) also were placed with the core stone, in a section extending beneath the crown at 1V:1H side slopes. The general purpose of filler stone is to decrease permeability and reduce sediment transport through the structure. The cover stone size was selected based partly on Hudson's slope stability equation and partly for economic reasons. A total of 19,280 tons of stone was placed at a cost of $164,700.
1985	The dike presently is considered to be in good condition.

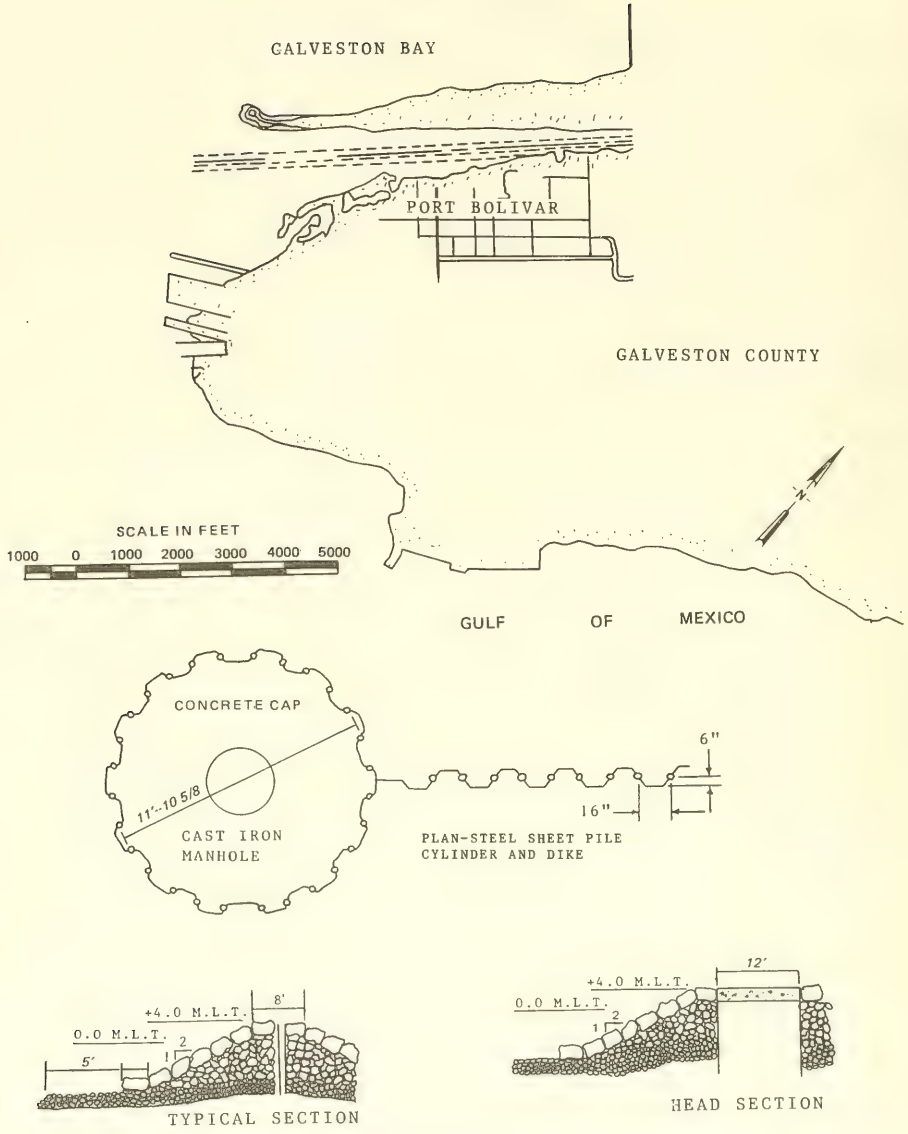

Figure 3. Location, plan view, and typical sections of Port Bolivar jetty

Table 3

Galveston Harbor Jetties

Galveston, Texas

Date(s)	Construction and Rehabilitation History
1874-1879	The first attempt at constructing jetties was begun by placing cement covered gabions over distances of 9,700 and 2,200 ft on the north (Bolivar Point jetty) and south (Fort Point jetty) sides of the inlet, respectively. An additional 500 ft of north jetty was constructed of timber piling at its landward end. The gabions were 6 ft high and wide, from 6 to 12 ft long, and filled with dredged sand once positioned. The jetties were submerged, extending no higher than mean low water (mlw), with the majority from 5 to 6 ft below mlw. The gabionnades were unsuccessful in either securing a deeper navigable channel or in accumulating sediments in their immediate areas. Various geometric arrangements of gabion placement were tried but proved unsuccessful. The gabions tended to settle and move laterally due to tidal and wave-induced water motions and related movements of bottom sediments. This method of construction was used due to lack of available stone and an inability to transport stone to the inlet.
1880-1885	A second attempt at a south jetty consisted of placing multiple layers of log and brush (fascine) mattress, each layer ballasted with stone riprap. A total of 22,550 lin ft was constructed with as many as four layers placed. The majority of the jetty was submerged with only its landward end above mlt. The mats were typically 1.5 ft thick and 30 to 120 ft wide at the base with narrower mats (15 to 60 ft wide) placed in the remaining layers. Approximately 400,000 sq yd of mattress and 9,000 tons of stone (roughly 50 lb/ft^2) were placed at a total cost of $968,000. By 1885, consolidation of the mattresses, settlement due to scour, and teredo damage had led to general deterioration and an average subsidence of almost 6 ft.
1887-1898	Rubble-mound jetties were constructed and completed to lengths of 25,600 and 34,800 ft on the north and south sides, respectively Figure 4). The south jetty was built during 1887-1893 and 1895-1897, and the north jetty was built during 1893-1898. The jetties were placed along the alignments of the earlier jetty attempts (the south jetty rubble mound being placed on top of the remains of the fascine mat jetty (from sta 84+64 to sta 310+14)), converging in the offshore direction to a distance of 7,000 ft. The jetties were built to +5 ft mlt, a typical crown width of 12 ft (but as large as 20 ft at the seaward end of the south jetty), and as steep as practicable side slopes (typically 1V:1H and up to 1V:1.5H at the seaward ends). The majority of the jetties were constructed using sandstone riprap varying in size from 20 lb to 3 tons. Granite blocks, varying in size from 0.75 ton to 10 tons and more, were used as the cover layer

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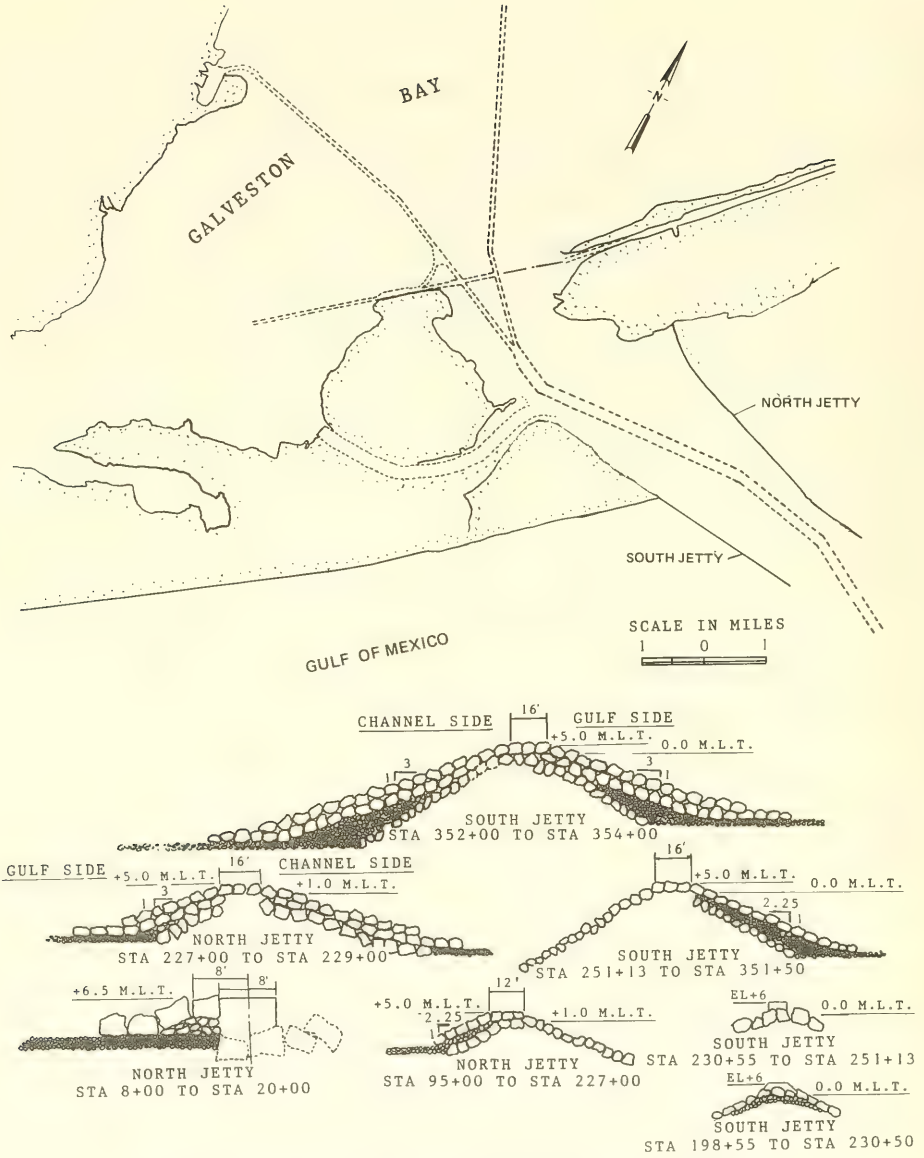

Figure 4. Plan view and typical cross sections of Galveston Harbor jetties

Date(s)	Construction and Rehabilitation History
1887-1898 (cont.)	on the north jetty and seaward 15,000 ft of the south jetty. A portion of the south jetty core from sta 95+64 to sta 133+24 consisted of clay materials, but this type of construction was abandoned due to increasingly difficult methods of placement as the jetty advanced into deeper water. The general method of construction involved extending an apron of large (outside edges) and small sandstone riprap followed by a core of small sandstone riprap up to mlt, placing the granite blocks on the core side slopes, and then placing the remaining core stone and completing the cover layer. Most of the jetty construction was in water depths of less than -12 ft mlt, with the other few thousand feet of each jetty in deeper water. The jetties' seaward ends terminated at about the -27 ft mlt contour. The north and south jetty were completed using approximately 1,117,000 and 807,000 tons of stone at total costs (adjusted to 1897 price index) of $3,484,000 and $2,567,000, respectively.
1902-1909	Following the hurricane of September 1900, repairs were made to the jetties. During 1907-1909 the south jetty was extended from sta 348+00 to sta 356+00. Nearly all of the south jetty repairs were located at its landward end between 6+00 and 143+63 and its seaward end between sta 220+00 and sta 348+00. Granite blocks weighing 5 to 7 tons were placed on the landward section and large (8- to 10-ton) and small (less than 8-ton) granite riprap were used on the seaward section. The south jetty extension was built up to +5 ft mlt with a maximum top width of 20 ft and 1V:1.5H side slopes. The core stone consisted of pieces less than 3 tons in weight placed on a 4-ft-thick apron of 20- to 120-lb stone. The cover layer stone placed below and above -15 ft mlt averaged 6 (minimum of 3) and 10 tons, respectively. The south jetty repairs and extension required 128,400 and 77,700 tons of stone placed at total costs of $387,000 (estimate) and $284,000, respectively. In 1908, a concrete cap was placed on the south jetty between sta 144+00 and sta 200+00 using 1,680 cu yd of concrete and 2,409 tons of chinking stone at a cost of $48,600. The majority of the north jetty repairs were completed during 1903-1905 with 105,000 tons of 10- to 12-ton stone placed between sta 9+00 and sta 255+00. During 1907-1909 minor north jetty repairs were made between sta 80+00 and sta 285+00 using 11,600 tons of stone. Total cost of the north jetty repairs was $450,000.
1909-1915	Minor repairs were made to the south jetty following the storm of July 1909 which damaged sections at its landward (sta 0+00 to sta 144+00) and seaward (sta 300+00 to sta 346+00) ends. A total of 22,500 tons of stone was placed, and several thousand tons of displaced cover stone were reset. Total repair cost was $131,000.
1915	A hurricane during August caused some damage to the jetties, but no subsequent work was undertaken. The north jetty received the most

(Continued)

Table 3 (Continued)

Date(s)	Construction and Rehabilitation History
1915 (cont.)	damage with numerous gaps (exposed core) at its landward end, from sta 10+00 to sta 18+00, and seaward of sta 141+00. The south jetty needed repairs seaward of 279+00. Estimated stone quantities needed to repair the north and south jetties were 46,000 (reset 38,000) and 4,200 (reset 1,000) tons, respectively.
1925-1927	During 1925-1926, the full length of the north jetty was repaired using 44,000 tons of stone at a cost of $305,000. The seaward end of the south jetty between sta 293+00 and sta 354+00 was repaired in 1927. Cost for placing 5,200 tons of stone was $47,600.
1933	A total of 430 tons of cover stone was placed on the south jetty.
1935-1936	An asphaltic concrete cap was placed on portions of both jetties, and a concrete cap was placed between sta 0+00 and sta 20+00 at the north jetty's landward end. The majority of the asphaltic cap was placed on two sections of the south jetty, near the existing shoreline from sta 196+55 to sta 230+59 and near the outer end from sta 345+08 to sta 347+98. The north jetty was capped at two existing low points or gaps from sta 144+15 to sta 145+75 and sta 177+00 to sta 178+00. Prior to the cap a seal course of asphaltic concrete was placed in the void spaces. The cap had a crown elevation of +4.7 ft, a crown width of 8 ft, and 1V:1H side slopes. The capping cost was $135,000 and used 12,280 tons of asphalt. The north jetty concrete cap was placed to an elevation of +6.5 ft mlt, an 8-ft crown width, and vertical sides. Stone totaling 9,200 tons also was placed at the north jetty's inner end bringing the total cost to $82,700.
1940-1942	Repairs were made to the north jetty with 15- to 150-lb core stone and 6- to 10-ton cover stone placed between sta 135+00 and sta 253+00 (near seaward end). A total of 22,300 tons of stone (87 percent cover) was placed and 600 cover stone reset. A concrete cap was placed on the south jetty from sta 230+59 to sta 251+12. The rectangular cap was 8 ft wide and had a crest elevation of +6 ft mlt. The cap required 800 tons of chinking riprap and 3,163 cu yds of concrete. The seaward section of the south jetty asphalt cap was destroyed during heavy wave action in 1941. About 7,000 tons of cover stone were placed at this section and other damaged areas. Total cost of the capping and armor stone repairs was $65,300 and $264,400, respectively.
1944	The shore end of the north jetty was repaired using 610 tons of core stone for a total cost of $5,700.
1962-1966	The north jetty was rehabilitated from sta 8+00 to sta 229+00, and the south jetty was rehabilitated from sta 251+13 to sta 354+00. Stone was placed on the gulf side slope and crown of each jetty

(Continued)

Table 3 (Concluded)

Date(s)	Construction and Rehabilitation History
1962-1966 (cont.)	(Figure 4). The outer 200 ft on each jetty was built as a head section with stone placed over the entire cross section. The design geometry was positioned 4 ft gulfward of the existing jetty center line with a top elevation of +5 ft mlt, a 3-stone-wide crown, and side slopes of 1V:2.25H and 1V:3H on trunk and head sections, respectively. The sections were built upon a 2- to 3-ft-thick blanket of 0.5-in. to 200-lb stone. The blanket extended beyond the cover layer toe distances of 10 and 50 ft for trunk and head sections, respectively. Core stone, typically 200 to 2,000 lb in size, then were placed providing the necessary side slope. One layer of cover stone was placed, except on the head sections, which used a double layer. Cover stone varied from a maximum of 16 to 18 tons at the heads to minimums of 2 and 6 tons at the north and south jetty landward ends, respectively. To decrease jetty permeability, 0.5- to 4-in. filler stone was placed in the crown area beneath the cover layer. Prior to the repairs, the jetties were in a general state of deterioration with much of the south jetty and several spots of the north jetty at or below +3 ft mlt. In many cases core stone was exposed, or cover layer stone was not tightly interlocked. Due to these conditions and use of large core stone during original construction, the jetties were considered too pervious to wave, tide, and sediment motions. Scour on the channel side of the north jetty was evident from sta 50+00 to sta 190+00 where the authorized 30-ft-deep channel made its closest approach to either jetty. Along this section water depths were typically 40 ft or greater within 100 ft of the jetty center line, while on the gulf side the typical water depth was 10 ft. This was a major reason for repairing the gulf side of the north jetty, since the quantity of stone required would be much smaller. The total costs for rehabilitation of the north and south jetties were $3,440,000 and $2,564,500, respectively. Although data on complete stone quantities were not found, partial quantities and several similar construction or repair projects (with known stone quantities) built during this time frame yield an estimate of from 600,000 to 1,200,000 tons of stone placed.
1986	The jetties have received no maintenance or repairs since rehabilitation in the 1960's and are considered to be in good condition. The present channel is authorized at 40- and 42-ft depths between inner and outer jetty sections, respectively.

Table 4

Freeport Harbor Jetties

Freeport Harbor, Texas

Date(s)	Construction and Rehabilitation History
1881-1885	Early improvements at the mouth of the Brazos River consisted of a parallel pair of fascine mat jetties, spaced 540 ft apart. The mats were ballasted with stone and concrete. By 1885 the north and south jetties were 3,600 and 4,350 ft long, respectively, with several hundred feet of each raised above mhw. Money appropriated to the project during this period totaled $142,100.
1889-1899	The Brazos River Channel and Dock Company (non-Federal interests) undertook the job of finishing the channel and jetties. The Federal improvements had been suspended due to lack of funds. The company spent about $1.5 million on channel and jetty construction; but again, due to lack of funds, the work was suspended. The work consisted of placing brush mats ballasted with 100- to 300-lb stone, adding larger riprap up to mlt, and covering with stones weighing from one to several tons. The overall lengths of the north and south jetties were 4,708 and 5,018 ft, respectively (Figure 5).
1900	The project returned to Federal control and the jetties underwent repairs. Riprap stone and 5- to 11-ton stone blocks were placed. Riprap-filled timber cribs were used along landward sections of the jetties. The repairs were halted by the hurricane of September 8 which damaged significant portions of the jetties. A total of 22,570 tons of stone and 14,340 lin ft of timber was placed for a total cost of $73,500.
1903-1908	The jetties were repaired under three separate contracts using 41,080 tons of stone at a total cost of $146,600.
1912	The north jetty landward end, from 0+00 to 10+00, was repaired using 3,290 tons of stone and capped with concrete. Total cost was $18,700. The jetties were considered to be complete at this time.
1918-1920	Repairs were made from sta 10+00 to sta 43+00 on the north jetty and sta 13+20 to sta 42+00 on the south jetty. Stone on the existing cover layer was reset, and 15,130 tons of riprap and cover stone were added. Other jetty work included 900 lin ft of pile and brush dike and 1,040 lin ft of rock-filled cribs. Total repair cost was $131,400.
1924	The south jetty was repaired between sta 15+00 and sta 45+00 using 3,430 tons of stone at a cost of $24,570.

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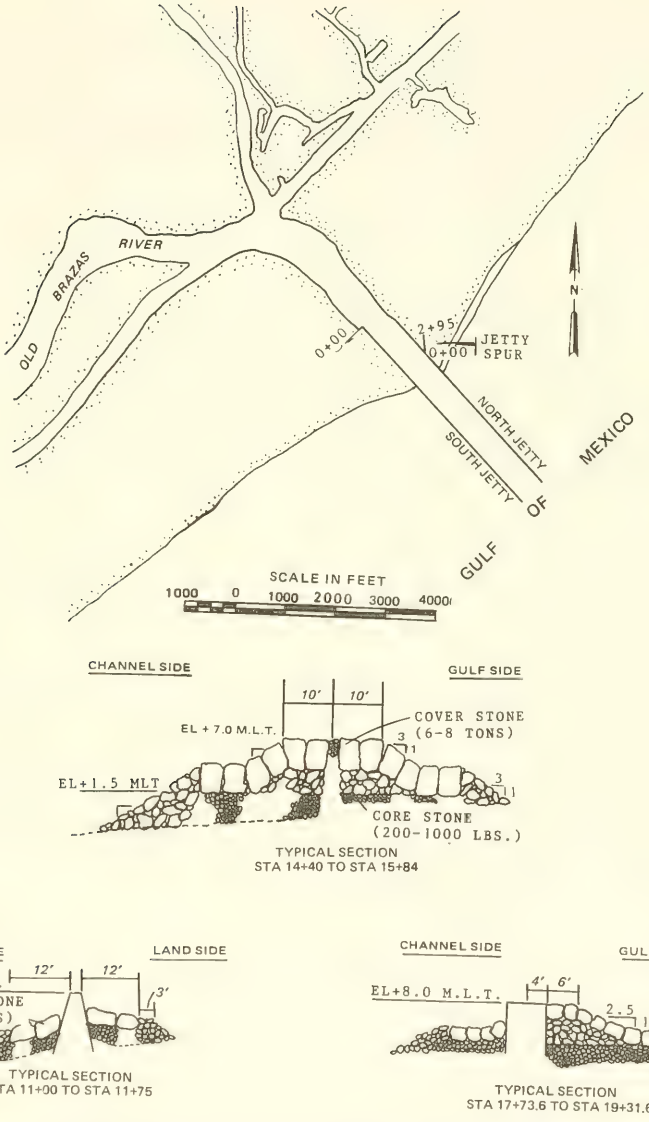

Figure 5. Plan view of Freeport Harbor jetties and typical south jetty repair sections

Table 4 (Continued)

Date(s)	Construction and Rehabilitation History
1929	For the purpose of flood control, the Brazos River was diverted to a point 5 miles south of the jetties. Due to the predominant southerly direction of littoral drift, the river ceased to be the major source of sediment supply to the jetties. Subsequent evolution of the shoreline showed a recession on both sides of the jetties, particularly on the south shore, where prior to the diversion the shoreline had advanced to within a few hundred feet of the jetty's seaward end.
1933	The jetties were repaired using 20,670 tons of mostly cover stone and resetting 1,740 cover stone at a total cost of $96,000.
1935	A concrete cap was placed on the north jetty from 9+00 to 25+00 using 1,653 cu yd of concrete. The cap was 6 ft wide with a top elevation of +7 ft mlt.
1936	The south jetty was capped from sta 0+00 to sta 45+80 using 6,085 cu yd of concrete. Top elevation of the cap was +8 ft mlt with widths of 2 and 8 ft landward and seaward of sta 15+90, respectively. The 2-ft-wide cap had 4V:1H side slopes, and the 8-ft-wide cap was rectangular. Total cost was $92,300.
1941	The north jetty was capped with 2,754 cu yd of concrete over a distance of 2,500 lin ft. The jetty now was capped from sta 0+00 to at least sta 42+50 with top elevations of +4 and +8 ft mlt landward and seaward of sta 8+30, and widths of 6 and 8 ft landward and seaward of 26+30, respectively. Total cost was $47,300.
1964	An inspection of the jetties indicated that although the concrete caps were in good condition, adjacent and underlying stone had consolidated or shifted leaving void spaces beneath the caps. The south jetty was in more immediate need of repair, mostly in the general vicinity of the south gulf shoreline between sta 0+00 and sta 30+00. These repairs were needed to prevent continued scour and undermining along this section. Based on available funds, limited rehabilitation of the jetties was considered but was rejected due to potential project improvements which included moving and rebuilding the north jetty and channel deepening.
1968	Two sections of the south jetty, from sta 11+00 to sta 11+75 and sta 17+70 to sta 19+30, were repaired by buttressing the concrete cap with stone and placing concrete between sta 18+00 and sta 19+05 (Figure 5). The landward section was subjected to undermining and piping beneath the cap. The cap on the outer section had collapsed, due to undermining, with about 20 ft at +1 ft mlt and the remainder between +1 and +8 ft mlt. The concrete was placed to the original dimensions of +8 ft mlt and an 8-ft width. Stone was placed on the gulf side of the cap to +8 ft mlt, a 6-ft top width and 1V:2.5H side

(Continued)

Table 4 (Continued)

Date(s)	Construction and Rehabilitation History
1968 (cont.)	slope. The remaining repairs consisted of buttressing the cap with 12-ft-wide bedding and cover stone layers. A 3-ft-wide layer of toe protection was placed along the outer edge of the repair sections. Stone sizes were 6 to 8 tons for the cover layer, 200 to 1,000 lb for the core (placed on seaside of outer section only) and toe protection, and 0.5 in. to 200 lb for the approximately 3-ft-thick bedding layer. Cost totaled $65,300 using 4,410 tons of stone.
1977	Minor repairs were made at a total cost of $9,200. (No details are available.)
1984	Two sections of the south jetty were repaired (Figure 5), and a 295-ft-long rubble-mound spur was placed at sta 8+40 on the north jetty's landward side. The south jetty repairs, from sta 14+40 to sta 15+85 and sta 19+20 to sta 20+20, consisted of a +7 ft mlt crown elevation, a composite width (including the cap width) of 20 ft and 1V:3H side slopes. A bedding layer of 0.5-in. to 200-lb stone was placed to +1.5 ft mlt and extended 26.5 ft from the jetty center line. Stone sizes were 6 to 8 tons for the cover layer and 200 to 1,000 lb for the core and toe protection. The toe protection was placed on a 1V:3H slope along the outer edge of the cover and bedding layers. The spur projected landward from the north jetty at a 30-deg angle and was built to an elevation of +6 ft mlt, a 5-ft top width, and 1V:1.5H side slopes. One-half inch to 200-lb blanket stone were used, except for a 90-ft section adjacent to the jetty. Single 4- to 6-ton stones were placed along the crown. The purpose of the spur was to minimize sand movement over the lower (+4 ft mlt) landward jetty section that was building a channel side shoal with the potential for future channel encroachment which would require subsequent maintenance dredging.
1986	Except for the more recent repair sections, the jetties are in poor condition, with many voids under the concrete caps and numerous cracks in the caps themselves. Jetty rehabilitation has been delayed pending authorized project improvements which include relocating the north jetty and channel deepening.

Table 5

Colorado River Jetties

Mouth of the Colorado River, Texas

Date(s)	Construction and Rehabilitation History
1984-1986	As part of navigational improvements, two rubble-mound jetties were constructed at the mouth of the Colorado River (Figures 6 and 7) providing protection for the 15- by 200-ft entrance channel. The south jetty is 1,450 ft long, and the north jetty, which contains a rubble-mound weir, is 2,650 ft long. The north jetty weir section begins 410 ft from landward end, at about the mlt contour, and extends 1,000 ft seaward to about the -8 ft mlt contour. The seaward ends of the north and south jetties are about 1,800 ft apart and situated in water depths of approximately -12 and -5 ft mlt, respectively. The jetty design incorporated an impoundment basin on the channel side of the north jetty to trap littoral drift material passing over the weir. The basin, initially dredged to a capacity of 740,000 cu yd, will be dredged periodically and the material deposited downdrift of the jetties. The crown elevations of the weir section and remaining jetty sections are 0 and +8 ft mlt, respectively. The design crown width and side slopes are 16 ft and 1V:3H, respectively. The typical jetty trunk section (Figure 7) consisted of a 2- to 3-ft-thick bedding layer of 0.5-in. to 200-lb stone, 200- to 1,000-lb core stone (2,000-lb maximum on the seaward leg of the north jetty), and a single layer of rectangular granite cover stone. The 200-ft-long head sections (at the seaward ends) were similar to the trunk sections except for a double layer of cover stone on the side slopes and a 5-ft-thick bedding layer on the north jetty. The cover stone varied in size from 4 to 6 tons at the landward ends to maximums of 16 to 18 tons and 10 to 12 tons at the seaward ends of the north and south jetties, respectively. To buttress the armor layer at the slope toes, the outer two to three cover stones were to be placed horizontally on the bedding layer. Cover stone sizes were selected using design wave heights of up to 17.6 ft (north jetty head) and Hudson's slope stability formula. The permeability of the jetties was decreased by chinking a section of the core stone, extending the full width of the crown and downward on 1V:1H slide slopes, with 0.5- to 4-in. filler stone. The absence of a core stone section was the only difference between the weir and trunk sections. Toe protection stone was placed on all sections of the jetties, buttressing the bedding layer and outermost cover stone (thus the thickness varied from 5 to 9.5 ft). The width of the toe protection section was 5 ft except on the head sections where it was 10 ft, and the design outer side slope was 1V:1H. The stone size was the same as the adjacent core stone (weir section used 200- to 2,000-lb stone). Transition sections, 100 ft long, were provided for changes in grade (or stone geometry) among weir, trunk, and head sections. Approximately 490,000 cu yd of material from the channel and deposition basin were to be used as fill on the west side of the channel and shoreline

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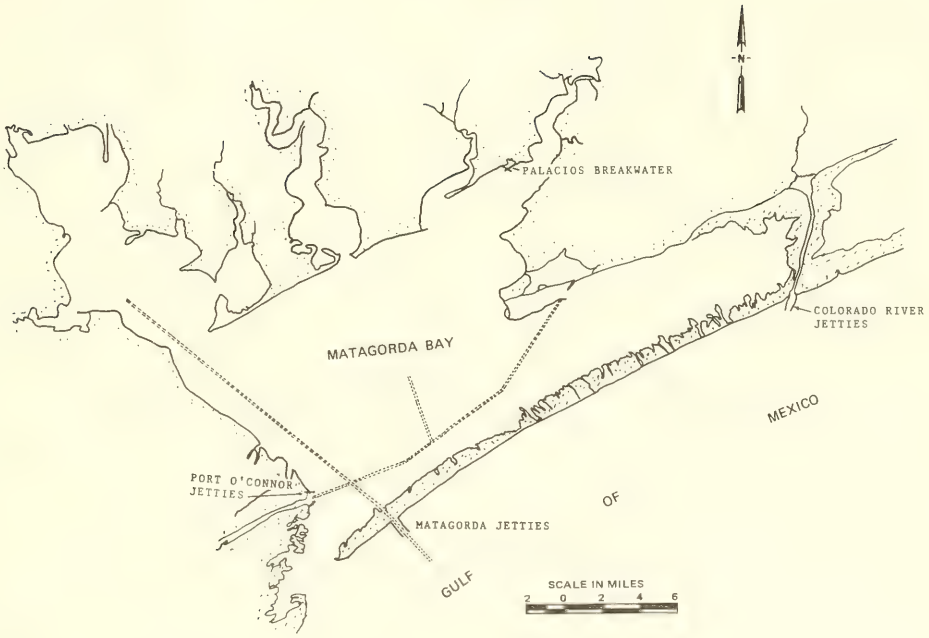

Figure 6. Plan view of Matagorda Bay and locations of the Colorado River, Palacios, Matagorda, and Port O'Connor projects

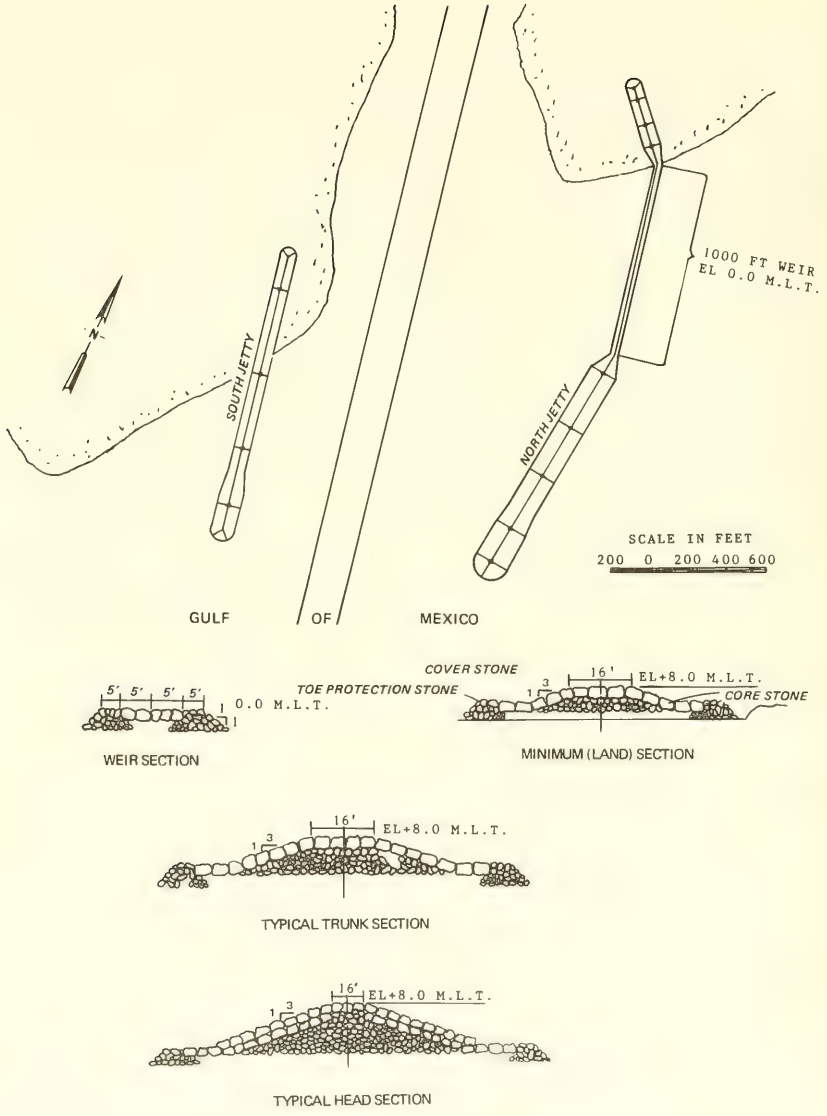

Figure 7. Plan view and typical cross sections of Colorado River jetties

Table 5 (Concluded)

Date(s)	Construction and Rehabilitation History
1984-1986 (cont.)	prior to construction of the south jetty. This material was placed to +5 ft mlt and at the root of the jetty was placed to +8 ft mlt. The maximum ground elevation allowed for jetty construction was mlt, thus some excavation was required at the landward ends. Prior to construction, the total amount of stone and costs were estimated at 248,000 tons and $7,200,000, respectively.

Table 6

Palacios Breakwaters

Palacios Harbor, Texas

Date(s)	Construction and Rehabilitation History
1966	Two rubble-mound breakwaters were constructed to lengths of 1,700 and 330 ft on the east and west sides, respectively, of the Palacios channel entrance (Figures 6 and 8). The purpose of the structures was to reduce wave energy entering the harbor and shoaling in the harbor slips and entrance channel. The breakwaters were constructed with a core and 2-ft-thick bedding layer of 0.5-in. to 200-lb stone. The core stone was placed to an elevation of +2 ft mlt, a width of 12 ft, and side slopes of 1V:3H and 1V:2H on the outer 700 ft of the east and remaining breakwater sections, respectively. A single layer of 2- to 4-ton cover stone was used on the breakwaters, with the exception of the outer 590 ft of the east breakwater which was covered with 4- to 6-ton stone. Some toe protection was provided by placing one to two cover stones at the base of the side slopes and extending the bedding layer 5 ft beyond the cover stone.
1970	The shoreline, made up of clay banks, was eroding in the general vicinity of the west breakwater. Rubble stone was placed along the shoreline on either side of the breakwater. (No details are available.)
1983	The breakwaters were inspected and considered to be in good condition.

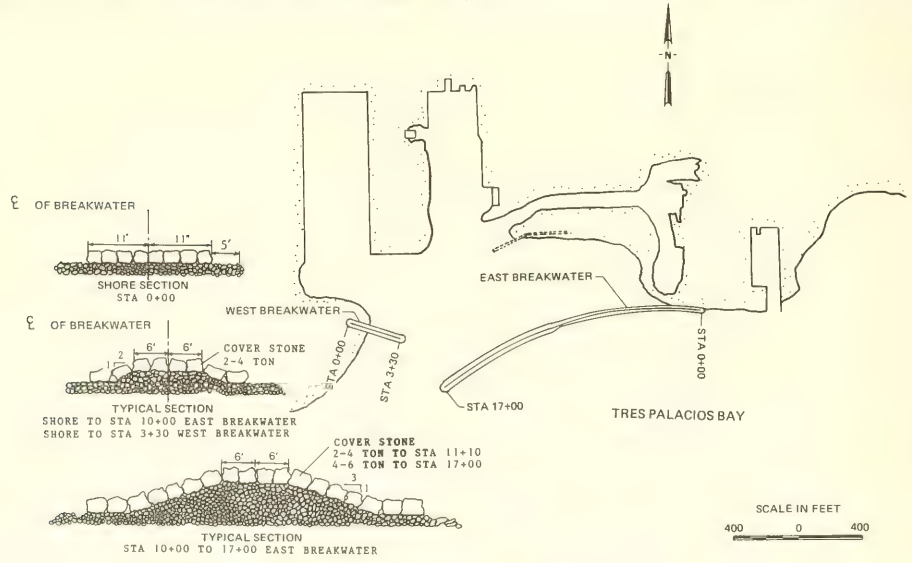

Figure 8. Plan view of Palacios Harbor and typical breakwater cross sections

Table 7

Port O'Connor Jetties

Port O'Connor, Texas

Date(s)	Construction and Rehabilitation History
1939	Located on Matagorda Bay, the north and south jetties (2,256 and 2,200 ft long, respectively) were constructed using steel sheet piles placed to an elevation of +4 ft mlt (Figures 6 and 9). The jetties, which converge to a distance of 800 ft at their seaward ends, provide shoaling protection for the 12- by 250-ft Gulf Intracoastal Waterway channel. The outer ends of the jetties were protected by 16-ft-diam sheet-pile cylinders filled with sand and capped with concrete (1 ft thick). Stone blankets (4 ft thick and 9 ft wide) were placed at the base of the cylinders. The total cost of jetty construction was $130,700, which included placing 81,500 sq ft of sheet pile and 950 tons of stone.
1950	Minor maintenance work was done for a total cost of $3,000. At the landward ends riprap was placed in a layer about 2 ft thick, 16 ft wide, and 100 ft long. The outer 300 ft of the north jetty was bracketed with timber wales bolted near the top of the sheet piles. Pile interlocking had become ineffective due to corrosion.
1964-1965	The jetties were rehabilitated by placing a rubble-mound cross section (Figure 9) along the outer 800- and 1,200-ft sections of the north and south jetties, respectively. In addition, scour protection was added to the remainder of the south jetty channel side, and shore protection was added at the landward ends of the dikes. The rubble-mound sections, with the existing jetties at the center line, were placed to an elevation of +4 ft mlt; side slopes were 1V:2H, and the crown width was approximately 10 ft (two cover stones wide, one on either side of the sheetpiling). The section was built up on a 2-ft-thick bedding layer (3 ft at seaward end) of 0.5-in. to 200-lb stone, a core of 200- to 1,000-lb stone, and a single layer of 2- to 4-ton cover stone. Filler stone (0.5 to 4 in.) also was placed with the core stone (a section 3 ft wide on either side of the sheetpiling and extending downward at 1V:1H side slopes). The bedding layer extended from 5 ft (landward) to 15 ft (seaward) beyond the toe of the cover stone layer. The landward 700 ft of south jetty bay side rubble mound consisted of a 2-ft-thick bedding layer placed between 0 and +2 ft mlt followed by a 2-stone-wide cover layer (+4.5 ft mlt crest elevation). South jetty scour protection was placed on 950 ft of the channel side (landward of the rubble-mound section) and consisted of a 2-ft-thick by 10-ft-wide layer of 0.5-in. to 200-lb stone. The north jetty was extended 50 ft landward, and a 30-ft-long perpendicular spur was added at the landward end (bay side) of the south jetty. This shore protection used 0.5-in. to 200-lb stone placed between 0 and +4 ft mlt with a 4-ft crown width and 1V:2H side slopes. At the

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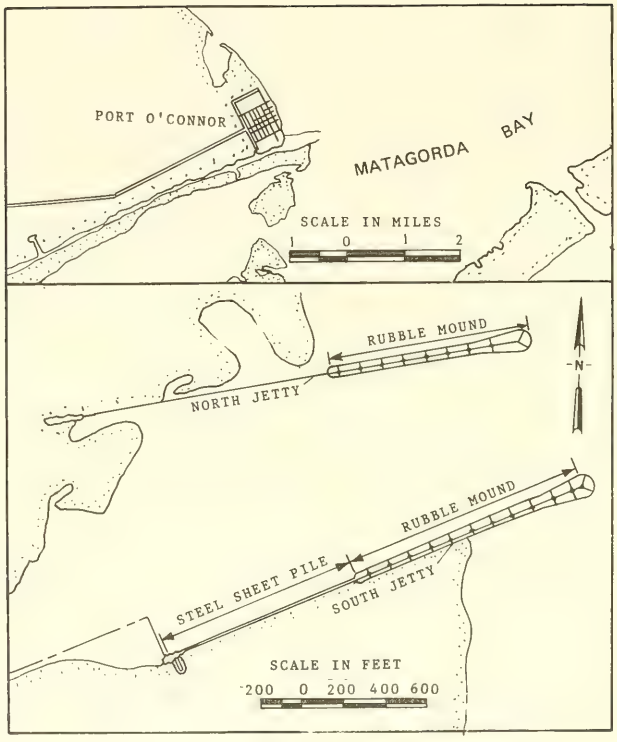
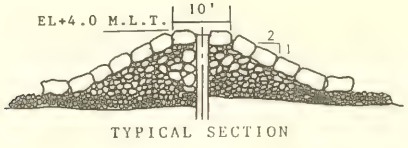
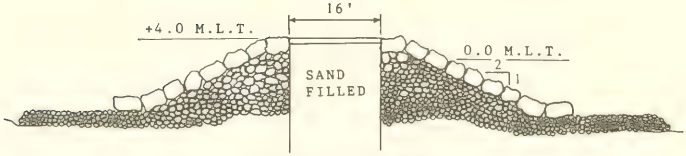




TYPICAL SECTION



HEAD SECTION

Figure 9. Location, plan view, and typical sections of Port O'Connor jetties

Table 7 (Concluded)

Date(s)	Construction and Rehabilitation History
1964-1965 (cont.)	time of the repairs the jetties were in fair condition (mostly general corrosion), except at their outer ends where scour and active soil pressures were evident, and the shoreline was eroding at the landward ends. The cover stone size was determined from Hudson's slope stability formula and a maximum depth-limited wave height of 12 ft. Existing elevations along the jetties varied from +2 to -11 (seaward ends) ft mlt. The rehabilation cost was $397,800 and required 46,910 tons of stone.
1971	Riprap stone (0.5 in. to 200 lb) was placed on the north jetty landward end. The shoreline had eroded leaving a gap of approximately 50 ft. A total of 600 tons of stone was placed at a cost of about $9,000.
1984	Except for general deterioration (corrosion) at several locations of the exposed sheetpiling, the jetties were considered to be in good condition (visual inspection). The present overall lengths of the north and south dikes are 2,300 and 2,250 ft, respectively.

Table 8

Matagorda Jetties

Matagorda Peninsula, Texas

Date(s)	Construction and Rehabilitation History
1963-1966	As part of the Matagorda Ship Channel project, twin rubble-mound jetties were constructed from Matagorda Peninsula into the Gulf of Mexico (Figure 6). The east and west jetties were 5,900 and 6,000 ft long, respectively, spaced 2,000 ft apart, and terminated at approximately the -24 ft mlt contour. The jetties provide protection for the 38- by 300-ft entrance channel. The design cross sections (Figure 10) consisted of a 16-ft crown width at +8 ft mlt and side slopes of 1V:2H and 1V:3H on the trunk and head sections, respectively. The head section on each jetty was 200 ft long, followed by a 100-ft-long transition tying into the trunk section. The typical jetty cross section was built on a bedding layer of 1/2-in. to 200-lb stone, varying in thickness from 2 ft at the landward end to 5 ft at the seaward end. To provide scour protection, the bedding layer extended beyond the toe of the cover stone a minimum of 5 ft at the landward ends to a maximum of 50 ft at the seaward ends. The core was built using 200- to 4,000-lb stone (except the landward 600 to 700 ft of the jetties which had a maximum stone size of 1,000 lb). To prevent the flow of littoral drift through the jetty, a section of the core (extending below the width of the crown at 1V:1H side slopes) was made impervious by adding 1/4- to 4-in. filler stone. A single layer of cover stone was placed on the jetty trunk sections, and a double layer of cover stone was placed on the head section side slopes. The outermost two to three cover stones were placed horizontally on the bedding layer, in effect buttressing the armor stone layer. The rectangular granite cover stone varied in size from 2 to 4 tons at the landward ends and 16 to 18 tons at the seaward ends. Cover stone sizes were selected using Hudson's slope stability formula, design wave heights of 10 to 22.6 ft, and a +13 ft mlt surge level. Under these conditions and no-damage criteria, calculated stone sizes ranged up to 48 tons. The largest available stone was less than 20 tons. Thus, the design used a stability coefficient of 6.8, allowing for a 10 to 20 percent damage level. The underlying foundation materials are mostly fine sands with some shell to a depth of about -60 ft mlt. During jetty construction the channel through the peninsula had progressed to the point that only a narrow earthen plug on the gulf side remained. On the night of 24 September 1963 the earthen plug was breached by a high tide in the gulf, and the resulting tidal currents soon caused severe erosion and scour at the outer ends of the partially completed jetties. The natural depths at the outer ends of the jetties were about -15 ft mlt prior to the breach but within a short period increased to about -40 ft mlt, during which time jetty construction was interrupted. The remaining jetty sections were completed under a new contract starting in 1964. Construction of the jetties, a north dike, and channel revetments totaled $13,200,000 using approximately 2,000,000 tons of stone.

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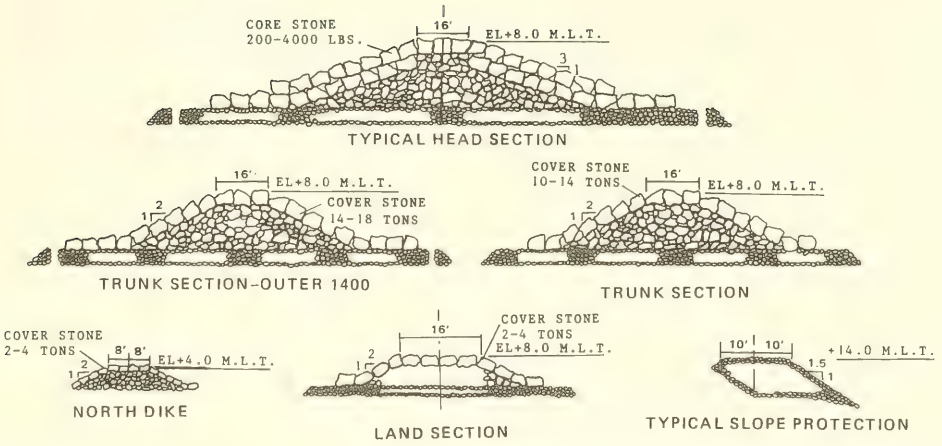

Figure 10. Typical cross sections of Matagorda Ship Channel jetties

Table 8 (Concluded)

Date(s)	Construction and Rehabilitation History
1970-1972	Inspections during 1970-1971 showed that some 10 to 20 cover stones from the top layer on the slope around each jetty head had been displaced. Also, near the landward end of the north jetty, on its channel side, several cover stones had shifted down the slope. In 1972 repairs were made to the jetties by resetting existing cover stone and placing additional cover stone at these sections and possibly others. No other details are available.
1980	An inspection showed that the north and south jetty heads required resetting of about 15 and 40 cover stones, respectively. Also three sections near the landward channel side of the south jetty showed some slippage of the cover layer, exposing the underlying core stone. The remaining jetty sections were considered to be in good condition.
1984	The jetties were inspected and considered to be in good condition except for 15 to 20 displaced cover stones at the head of each jetty.

Table 9

Aransas Pass Jetties

Aransas Pass, Texas

Date(s)	Construction and Rehabilitation History
1868-1899	During this period several attempts were made to secure a navigable channel at Aransas Pass by means of structural improvements. In 1868 a 600-ft-long timber crib dike (filled with brush and stone) was constructed on St. Joseph Island (north side) by local interests at a total cost of $9,900. By 1871 storm activity essentially had destroyed the dike. From 1880 to 1885, the Federal government constructed the "Mansfield" or "Old Government" jetty on Mustang Island (south side). The jetty was about 4,000 ft long and built using brush mattresses overlaid with stone. The cost of the jetty and additional shoreward improvements was $383,600. During 1888-1889 a 2,725-ft-long riprap revetment (1.5 ft thick) was placed on Mustang Island, using portions of the previous (1880-1985) improvements at a total cost of $156,900. Between 1892 and 1896 private interests constructed the "Nelson" and "Haupt" jetties on the south and north sides of the pass, respectively. The Nelson jetty, constructed in 1892 to a length of 1,800 ft, consisted of a row of light cylindrical wooden caissons, 7 ft in diameter, filled with sand and stone, and riprapped to a certain extent. The cost for constructing the Nelson jetty was $53,800. The Haupt jetty was partially completed during 1895-1896 to a length of 5,750 ft. The jetty was built on fascine mats (40 to 50 ft wide) and covered with a 3-ft-thick layer of 100- to 1,000-lb sandstone. The similar sized core stone was placed to mlw and covered with 2- to 10-ton cap and face stone, resulting in a top width of 16 ft and 1V:1.5H to 1V:2H side slopes. About 1,250 ft of jetty was completed to the design section. The jetty was constructed as a detached structure (its inner end about 1,500 ft from shore) and shaped concave channelward (Figure 11). The detached feature was for the purpose of maintaining the tidal prism, and the curvature was intended to train the tidal flow and maintain a navigable channel via scour action. The prevailing thought here was the analogy of a river bend or oxbow. Approximately 25,500 sq yd of mattress and 57,700 tons of stone were used at a construction cost of $224,900; engineering costs brought the total to about $250,000. During 1886-1887 about 500 ft of the Old Government jetty were removed by blasting from the channel. These attempts at providing a 20-ft-deep navigable channel were unsuccessful, and the project was returned to government control in 1899.
1902-1906	During this period the Haupt jetty was repaired and completed using various sizes of stone riprap and crest blocks, typically 3 to 8 tons in weight. The majority of the 5,750-ft-long jetty was brought up to a crest elevation of +4 ft mlt. The construction costs were $468,900 for placing 119,470 tons of stone. During 1903-1904, a portion of the Old Government jetty was removed from the channel at a cost of $46,000.

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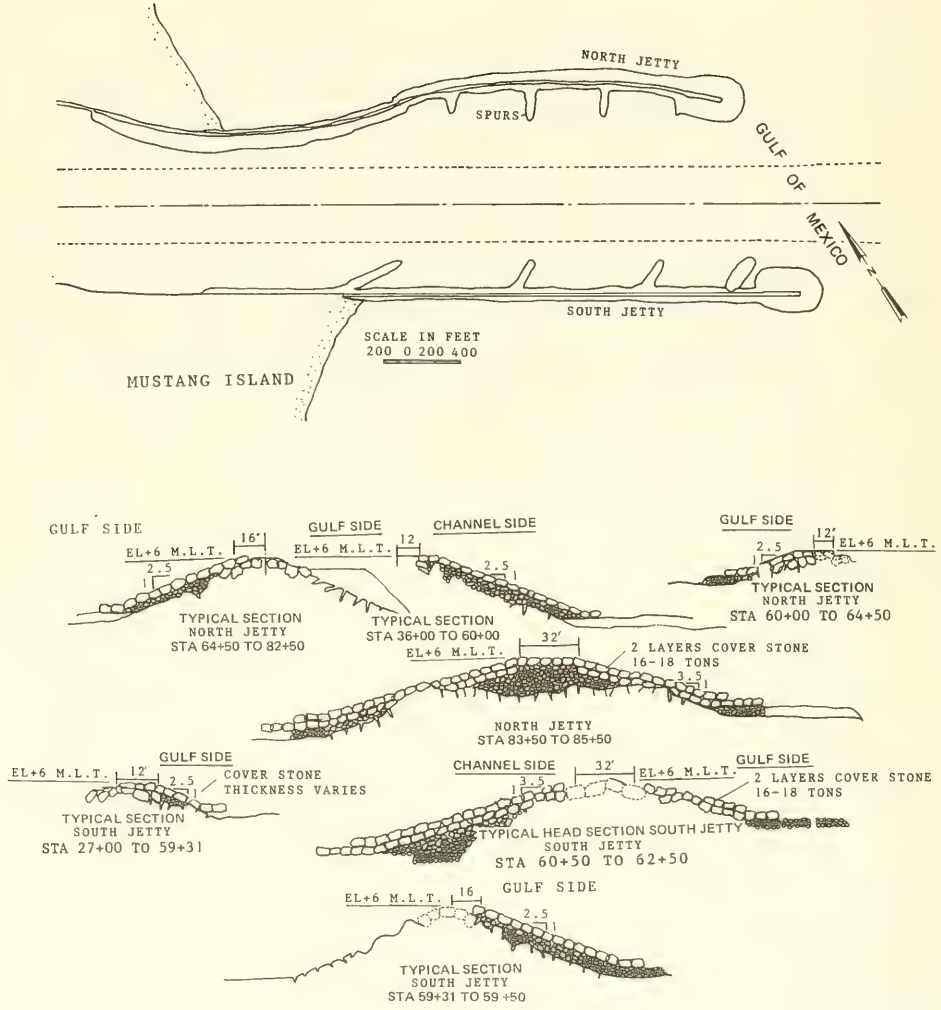

Figure 11. Aransas Pass jetties, plan view and typical cross sections

Table 9 (Continued)

Date(s)	Construction and Rehabilitation History
1908-1917	The north or Haupt jetty was repaired and extended 3,490 ft landward which closed the gap, and a 7,385-ft-long south jetty was constructed (Figure 11). The jetties were roughly parallel, spaced 1,500 ft apart, with the south jetty extending 1,150 ft seaward of the north jetty. The jetties were built up to +5 ft mlt and crest widths of 10 to 20 ft using small riprap (15 to 200 lb), large riprap weighing 200 lb to 7 ton, and crest stone greater than 7 tons comprised 7 percent of total. The total quantity of stone placed on the north and south jetties was 162,400 and 253,900 tons, respectively. These totals include minor repairs made during 1916-1917. The total cost for jetty improvements during this period was $1,544,500. In 1911, portions of the Mansfield and Nelson jetties were removed from the channel at a cost of $14,300. The authorized 20-ft channel depths were obtained during construction as the tidal flow and resulting bottom scour were gradually confined.
1922-1923	Four rubble-mound spurs were added on the north jetty channel side to reduce the amount of scour and undermining caused by the proximity of the channel. The spurs were built up to +3 ft mlt, spaced 600 ft apart, and extended 50 to 100 ft normal to the jetty axis. The outermost spur was about 1,000 ft from the seaward end of the jetty. A total of 25,070 tons of riprap stone was placed at a cost of $147,800. Minor repairs were made to the north jetty in 1923, consisting of 280 tons of stone for a cost of $1,300.
1927-1928	The outer 3,100 ft of north jetty and its spurs were repaired. A total of 18,070 tons of stone was placed at a cost of $122,900.
1934-1935	The jetties were repaired using 20,860 tons of stone at a total cost of $129,400.
1935-1936	Concrete caps were placed on 4,670- and 3,150-ft sections of the north and south jetties, respectively. The north jetty cap started 1,790 ft from its landward end, was 5 ft wide on the inner 1,800 ft, and 12 ft wide on the remainder. The south jetty cap started at its landward end, and the inner 1,000 ft was 5 ft wide with the remainder being 12 ft wide. The top elevation of the caps was between +6 and +7 ft mlt. A total of 5,030 and 4,160 cu yd of concrete was used on the north and south jetties, respectively. Total construction cost was $175,400.
1940-1943	The south jetty cap was extended 2,780 ft seaward using 6,630 cu yd of concrete for a total cost of $129,700. The cap was 12 ft wide with a top elevation of +6 to +7 ft mlt.
1942-1943	Repairs were made on sections of both jetties using core and cover stone. A total of 23,950 tons of stone was placed at a total cost of $223,000.

(Continued)

Table 9 (Continued)

Date(s)	Construction and Rehabilitation History
1950-1951	Repairs were made at a total cost of $566,700 using 16,940 and 13,570 tons of stone on the north and south jetties, respectively.
1954-1957	The jetties were repaired, and three spurs were constructed on the channel side of the south jetty. The majority (80 percent) of the jetty repairs used 8- to 13-ton cover stone; the remainder was mostly 25 to 2,000 lb, and the spurs were built using 25-lb to 10-ton (quarry-run) stone. The spurs were placed about 1,000 ft apart with the outermost approximately 2,400 ft from the jetty's seaward end. Each spur was about 200 ft long and extended seaward, offset from the jetty axis at a 30- or 60-deg angle. The spurs were needed to reduce scour and undermining of the jetty caused by tidal flows. Stone quantities were 19,300, 52,640, and 72,870 tons for the spurs, north and south jetties, respectively. The total repair and construction costs were $2,145,500.
1958-1959	Sections of the north and south jetties (2,150 and 355 ft long, respectively) were capped with concrete. These sections extended seaward from the existing caps, and it appears they terminated at the jetties' existing seaward ends. The condition of the outer 640- and 1,100-ft sections of the north and south jetties could not be determined from information at hand. The concrete was grouted throughout the cover stone void spaces lying between 0 and +6 ft mlt (the existing crest elevation). Prior to placing concrete, large voids were filled with 5- to 50-lb chinking stone. A total of 7,290 cu yd of concrete and 2,800 tons of stone was placed at a total cost of $387,600.
1961-1962	The passage of Hurricane Carla in September 1961 caused significant damage to the seaward ends of the jetties. The outer 300 ft of the north jetty, including the outermost 250 ft of concrete cap, essentially was destroyed. In 1962 the jetties were surveyed and inspected in preparation for planned rehabilitation. The concrete caps essentially were intact, although numerous cracks and sections of the caps had subsided. However, this was not a true indication of their general condition. There was significant subsidence of the side slope armor and underlayer core stone creating void spaces beneath the caps and exposing core stone on the steepened side slopes. The rehabilitation was recommended based on expected failure of several jetty sections, under storm conditions, leading to a loss of channel protection and increased shoaling. Scour and undermining were considered major sources of jetty deterioration. Center-line elevations varied from -10 to -35 ft mlt and from -10 to -20 ft mlt on seaward 800 and 1,000-ft sections of the north and south jetties, respectively. Scour holes were evident at their extreme seaward ends.

(Continued)

Table 9 (Continued)

Date(s)	Construction and Rehabilitation History
1964-1966	The jetties underwent major rehabilitation using the recommendations and design proposed in 1962 (Figure 11). The new seaward ends of the 4,950- and 3,550-ft-long repair sections terminated 790 and 1,135 ft from the original seaward ends of the north and south jetties, respectively. The south jetty repairs consisted of a rebuilt gulf side slope, a 200-ft-long head section, and a 250-ft channel side spur located 550 ft landward of the head. The north jetty repair section had the landward 2,410-ft channel side and adjacent (seaward) 2,250-ft gulf side slopes rebuilt. The final 300 ft were rebuilt as a transition and 200-ft head section. The head sections had a crown elevation of +6 ft mlt, a 32-ft crown width and 1V:3.5H side slopes. The 16- to 18-ton cover stone was placed as a double layer on the side slopes and single layer on the crown. The 200- to 4,000-lb core stone was partially supplemented with 0.5- to 4-in. filler stone (in a section extending beneath the crown at 1V:1H side slopes) for the purpose of decreasing structure permeability. The 0.5-in. to 200-lb blanket stone was placed in a 5-ft-thick layer and extended 50 ft beyond the toe of the cover layer. The jetty trunk sections were rebuilt to +6 ft mlt and a 1V:2.5H side slope. The crown extended two cover stones in width from the existing 12-ft-wide concrete cap sections or 14 ft from the center line of the north jetty grouted cap (1,800-ft section). The single layer of cover stone varied from a minimum of 2 to 4 tons at the south jetty landward end to a maximum of 16 to 18 tons at the jetty seaward ends. The blanket layer was placed in 3-, 4-, or 5-ft thicknesses and extended 10 ft beyond the toe of the cover layer. Prior to placing the core stone the existing void spaces were chinked with filler stone. The filler, blanket, and core stone size ranges were the same throughout the repair sections (see above). The south jetty groin consisted of core stone placed to -18 ft mlt, a 10-ft crown width, and 1V:1.5H side slopes. The core stone was placed on a 5-ft layer of blanket stone which extended 10 ft beyond the toe of the core stone. The total cost of rehabilitation was $3,367,000 and required 410,250 tons of stone. The jetty design was based on Hudson's slope stability formula, depth- and fetch-limited wave heights, and a maximum storm surge level of +13 ft mlt. The 18-ton maximum cover stone was inadequate for maximum design conditions but was selected for practical and economic reasons.
1967	Hurricane Beulah's passage in October displaced cover stone at several locations, with an estimated 100 pieces missing or displaced from each jetty. Near the landward ends of the jetties sand was washing or piping under the concrete caps and into the ship channel. It is not known whether this piping was due to the storm or if it had been a previous problem. These sections were located from sta 12+00 to sta 24+00 on the north jetty and from sta 10+00 to sta 25+00 on the south jetty (landward ends at sta 0+00).

(Continued)

Table 9 (Concluded)

Date(s)	Construction and Rehabilitation History
1970	The jetties were inspected after the August passage of Hurricane Celia. Displaced cover stone was noted at the seaward end of the north jetty (the convex portion of the north jetty's channel side) and a section of the south jetty's gulf side adjacent to and seaward of the existing shoreline. It was not known how much of the existing damage was caused by Hurricane Celia since no repairs were made subsequent to Hurricane Beulah.
1972	The jetties were repaired by adding and resetting cover stone on damaged sections noted during the 1970 inspection (see above). Repair areas on the north jetty channel side included 10 sections totaling 1,010 lin ft between sta 35+50 and sta 64+00, where 10- to 12-ton stone was added and the displaced 4- to 10-ton stone reset. At the north jetty seaward end displaced 16- to 18-ton stone were reset along 300 ft of channel and head semicircle side slopes. The south jetty's gulf side between sta 27+00 (existing shoreline) and sta 29+30 was repaired by adding 4- to 6-ton stone, and its channel side was repaired between sta 16+50 and sta 20+50 by adding 1,000- to 4,000-lb riprap stone. Total cost of the repairs was $129,500.
1978	Seven sections of the south jetty totaling 980 lin ft between sta 8+70 and sta 24+50 were repaired by placing stone on the landward side of the concrete cap. Scour beneath the cap had caused piping and removal of sand along its landward face. Although this condition had existed for several years, repairs were considered necessary due to the size of the scour holes and concern for human safety. The repairs consisted of placing a 1.5-ft-thick bedding layer of 0.5- to 6-in. stone extending 12 ft from the cap and covered with a 2.5-ft thickness (but not to project above the cap) of 200- to 1,000-lb riprap extending 8 ft from the cap. Total cost of the repairs was $60,700.
1984	The jetties were inspected and considered to be in good condition with the exception of 10 to 20 cover stones that were displaced along the channel side of each jetty's head section, displaced cover stone along the north jetty channel side, and settlement of some supporting stone beneath the concrete caps.

Table 10

Port Aransas Breakwaters

Port Aransas, Texas

Date(s)	Construction and Rehabilitation History
1973	Two rubble-mound breakwaters, the east 850 ft long and the west 1,290 ft long, were constructed to provide adequate protection from ship-generated (Corpus Christi Channel) and wind-generated waves entering the existing anchorage basin at Port Aransas (Figure 12). The typical cross section geometry (Figure 12) had a crown elevation of +6 ft mlt, an 8-ft crown width, and 1V:2H side slopes. Cover stone size was 1 to 6 tons. The core and 2-ft-thick bedding layer were made up of 0.5-in. to 200-lb stone. The landward 550 ft of the west jetty were constructed as a sand-fill dike, with a crown elevation of +4 ft mlt and a top width of 20 ft. A 21-ft-wide section of its 1V:5H seaward side slope was revetted with a 2-ft-thick bedding layer and cover stone layer (Figure 12). The revetted section was aligned with the breakwater section so that the tops were coincident at the harbor side of the crown width. The center line of the fill section was about 16 ft behind this point. The cover stone size was selected based on the lower cost of placing the 1- to 6-ton stone versus the 700- to 800-lb stone size required for slope stability (design waves of 8.7 ft and Hudson's formula). The breakwaters were constructed on a foundation of sands and silty sands.
1977	An inspection of the breakwaters indicated they were in good condition with the exception of the revetted section of the west jetty. Waves breaking over the shore protection had eroded the sand fill resulting in some minor settlement of the stone.
1984	The breakwaters were inspected and considered to be in good condition.

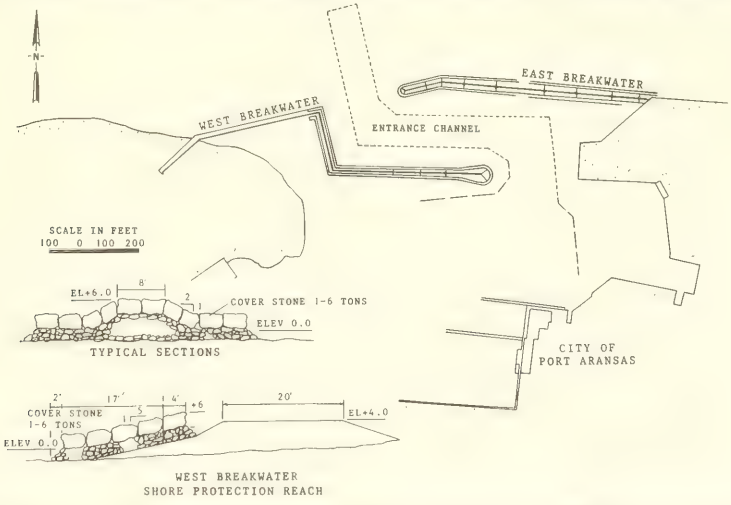

Figure 12. Port Aransas plan view and typical breakwater sections

Table 11

Port Mansfield Jetties

Port Mansfield, Texas

Date(s)	Construction and Rehabilitation History
1957-1961	Local interests dredged a channel across Padre Island and constructed two tetrapod jetties at the entrance to the Gulf of Mexico. The north and south jetties were 1,600 and 800 ft long, respectively, and spaced 1,000 ft apart (Figure 13). The tetrapods weighed 5, 8, and 16 tons each and were placed directly on the existing bottom to a cross section of +5 ft mlt, a 10-ft top width, and 1V:1H side slopes (Figure 13, inset). Within a year these jetties were no longer providing adequate channel protection. The tetrapods had subsided, the shore ends were in water 2 to 4 ft deep, scour channels existed along sections of both jetties, and extensive shoaling had occurred in the entrance channel. By 1961 the inlet had closed and the tetrapods were nearly submerged.
1962	Two rubble-mound jetties were constructed under Corps management and Federal funding as part of navigational improvements between Port Mansfield and the Gulf of Mexico (Figure 13). The north and south jetties (2,300 and 2,270 ft long, respectively) were constructed on the south sides of the existing tetrapod jetties. The parallel jetties, spaced 1,000 ft apart, terminated at approximately the -9 ft mlt contour. The jetties were staggered with the south jetty 490 ft east of the north jetty. The design geometry (Figure 13, inset) consisted of a +8 ft crown elevation, 16-ft crown width, and 1V:3H side slopes. The cross section was built on a 3-ft-thick bedding layer of 0.5-in. to 200-lb stone. The bedding layer was to extend beyond the ends of the cover stone layer, typically 2 ft at the landward ends to 15 ft at the seaward ends. The core was built up using 200- to 1,000-lb stone along landward sections (each several hundred feet long) and 200- to 4,000-lb stone along the remaining seaward sections. Jetty permeability was decreased by supplementing a midsection of the core with 0.5- to 5-in. filler stone. The geometry of this combined core stone extended below the full crown width at 1V:1H side slopes. The cubically shaped granite cover stone increased in size from 1 to 10 tons, between landward and seaward ends of each jetty, respectively. The seaward 100 ft of each jetty had an additional layer of 6- to 10-ton cover stone placed on the side slopes. Stone sizes were selected using Hudson's slope stability formula and depth-limited wave heights of up to 12 ft at the seaward ends (+6 ft mlt surge level). The foundation for the jetties consisted of various sand and clay layers, including a 10- to 15-ft-thick layer of soft clay. Soil tests indicated that the clay layer could consolidate up to 0.75 ft (seaward end), and total structure settlement on the order of 3 ft was expected (consolidation of the foundation and jetty materials). Total cost was $2,736,000 with 307,030 tons of stone placed and 10,000 tons of blanket stone stockpiled.

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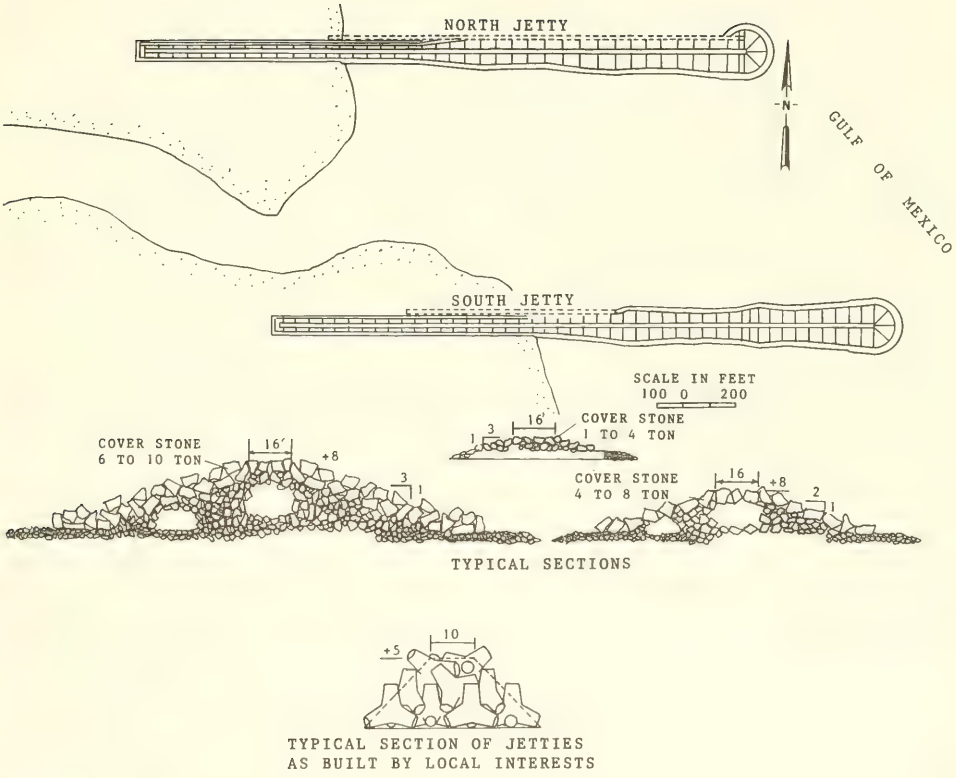

Figure 13. Plan view and typical cross sections of Port Mansfield jetties

Table 11 (Concluded)

Date(s)	Construction and Rehabilitation History
1963-1964	Landward sections on the channel sides of both jetties had scoured and lost blanket stone, allowing the outermost cover stones to shift, resulting in exposure of interior core and blanket stone. These sections were located where the bedding apron was 2 ft wide. The seaward side of the north jetty had a 10-ft-wide bedding apron and the south jetty, which had a 2-ft apron, was accumulating sediments along its seaward side. The exposed section varied in width from 6 to 10 ft on the south jetty and 2 to 4 ft on the north jetty.
1964-1965	Repairs were made to the jetties using 2- to 4-ton cover stone and resetting existing cover stone. Repairs were made also to sections of the channel revetment using 0.5-in. to 200-lb blanket stone and 2- to 4-ton cover stone. A total of 10,420 and 5,900 tons of cover and blanket stone, respectively, was placed (about 3,800 tons of cover stone used on the jetties) at a total cost of $191,000.
1967-1968	The shore ends of the jetties and adjacent shore protection received minor damages due to the passage of Hurricane Beulah in 1967. Repairs were made in 1968 using 780 tons of stone and resetting existing cover stone at a total cost of $18,900.
1980	The jetties were inspected and found to be in good condition, with the exception of some damage at their heads. The landward end of the south jetty was flanked by a channel maintained by tidal flows.

Table 12

Brazos Island Jetties

Brazos Island Harbor, Texas

Date(s)	Construction and Rehabilitation History
1882-1928	Unsuccessful attempts to stabilize the pass and provide a navigable channel were undertaken during 1882-1884 and 1926-1928. These improvements were authorized by River and Harbor Acts of 1880-1881 and 1919. Construction of a south jetty was started in 1882 by placing alternate layers of brush mats and 11-lb clay bricks. The bricks did not provide sufficient ballast, and construction was halted in 1884. The jetty, partially completed to a length of 3,955 ft, deteriorated rapidly during the next few months. During 1904-1905 a channel was dredged through the pass but was abandoned in 1906 due to excessive shoaling. North and south stone dikes (1,800 and 1,400 ft long, respectively) were constructed on each side of the pass during 1926-1927. The dikes were not successful in securing an increased channel depth (18- by 400-ft channel authorized).
1933-1935	The existing jetties (Figure 14) authorized by the River and Harbor Act of 1930 were constructed near the locations of the 1926-1927 stone dikes to lengths of 5,370 and 5,092 ft on the north and south sides, respectively. The jetties converge from their landward ends to a spacing of 1,200 ft then run parallel for approximately 2,500 ft, terminating at the -25 ft mlt contour. The typical cross section consisted of a 14-ft crown width at +6 ft mlt, 1V:1.5H side slopes, a riprap bedding layer, 15- to 4,000-lb core stone and 6- to 10-ton capstone. The jetties were constructed with 418,200 tons of stone at a total cost of $2,741,000.
1936-1937	Stone aprons were placed near the outer ends of both jetties. No details are available. Riprap stone totaling 7,400 tons was placed at a cost of $47,000.
1940-1943	Various sections of both jetties totaling 5,690 lin ft were repaired using new core and cover stone and resetting existing cover stone. Approximately 20,800 tons of new stone were used and 1,570 stones reset for a total cost of $244,100.
1954-1955	The jetties were repaired using new core and 8- to 16-ton cover stone, resetting existing cover stone, and capping with concrete. The concrete was placed above mlw throughout the void spaces in the cover layer, restoring the general crown elevation of the jetties. Total cost of the repairs was $859,000 using 20,300 tons of stone and placing 6,160 and 3,580 cu yd of concrete on the north and south jetties, respectively. The concrete capping extended from the existing shoreline to the jetties' seaward ends (roughly 3,000 lin ft on the north and 2,000 lin ft on the south).

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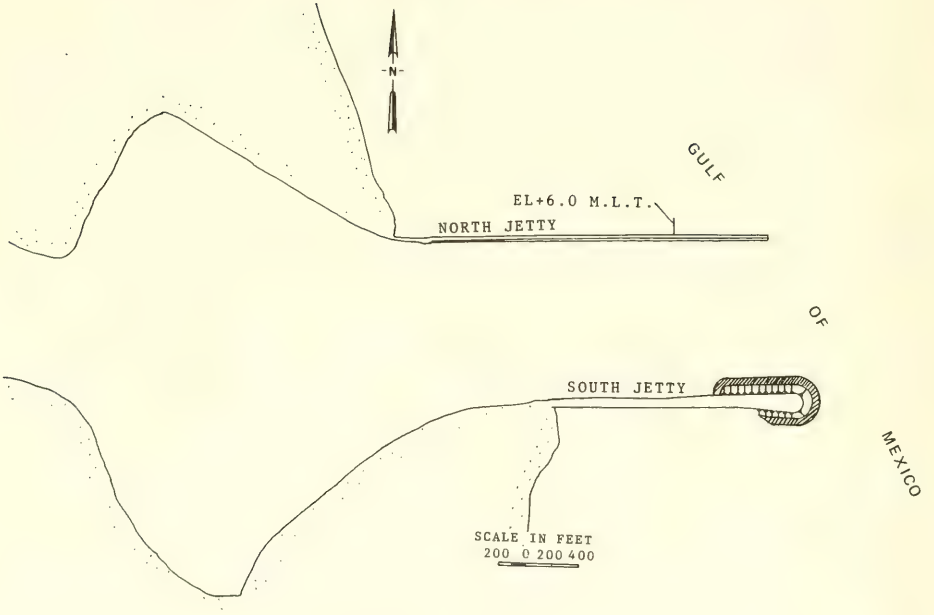

Figure 14. Plan view of Brazos Island jetties

Table 12 (Continued)

Date(s)	Construction and Rehabilitation History
1957-1959	The jetties were repaired at their seaward ends. New riprap, core, and 14- to 18-ton cover stone were used. Existing cover stone was reset, and concrete was placed (similar to previous capping). A total of 20,500 tons of stone and 600 cu yd of concrete were placed at a total cost of $268,000.
1961	Approximately 1,270 lin ft of stone embankment was placed along the section of channel shoreline adjacent to the landward end of the north jetty. The purpose of the embankment was to reduce shoreline erosion which threatened to flank the jetty. A 3-ft-thick layer of 0.5-in. to 200-lb stone was placed at about the mlt contour. The width of the layer was roughly 25 ft. Total cost of this shore protection was $40,500. In September several sections of the jetties were damaged during Hurricane Carla. The south jetty received the most damage. About 45 ft of its seaward end was severely damaged, and large holes developed under several sections of the concrete cap. The holes were caused by displacement and settlement of cover and core stone. Near its seaward end, about 200 ft of cap had collapsed and an additional 70 ft was severely damaged. On the north jetty major areas of damage occurred at its seaward end, with 190 ft destroyed and a 380-ft channel side section damaged by undermining near the landward end. The magnitude of stone displacement and undermining of the cap was much smaller on the north jetty. Damage to the seaward ends of the jetties was believed to be due partly to scour along the jetty toes and partly to the existing 1V:2H side slopes which were too steep for the existing cover stone and storm waves.
1965-1966	A 1,825-ft section of the south jetty was rehabilitated, and repairs were made to 580 ft of the north jetty. Starting from its seaward end the south jetty repairs extended a distance of 625 ft along both side slopes and continued for an additional 1,200 ft on its gulf side. The design geometry (Figure 15) consisted of a +6 ft mlt crown elevation, a 20- to 30-ft crown width (seaward end widest), 1V:4H side slopes on the 200-ft-long head section, and side slopes of 1V:2.5H and 1V:4H on remaining gulf and channel sections, respectively. A 3- to 5-ft-thick bedding layer of 0.5-in. to 200-lb stone was placed, extending from 10 to 50 past the toe of the new cover stone. (The thicker/wider layer was used on the 1V:4H sections.) The core stone varied from a minimum of 200 lb to maximums of 1,000 and 4,000 lb between landward and seaward ends, respectively. To reduce sand transport through the jetty, part of the gulf side core stone adjacent to the old cover stone was combined with 0.5- to 4-in. filler stone. The cover stone varied from 2 to 4 tons on the landward gulf side, increasing in size in the seaward direction to a maximum of 16 to 18 tons. The entire channel side was 16 to 18 tons). A double layer of cover stone was used on the side slopes of the head section. Additional repairs were made by

(Continued)

Table 12 (Continued)

Date(s)	Construction and Rehabilitation History
	breaking up the concrete cap at sections where underlying cavities had formed. The released cover stone was left in place and overlaid with new cover stone bringing the sections up to the +6 ft mlw design elevation. The north jetty repair, located approximately 3,500 ft from the seaward end, brought the channel side up to grade by placing blanket stone, resetting existing cover stone, and adding new 200- to 1,000-lb core stone and 2- to 4-ton cover stone. The 3-ft-thick blanket of 0.5-in. to 200-lb stone extended 10 ft beyond the toe of the cover layer. The section was brought up to +6 ft mlt and a side slope of 1V:2.5H. Water depths were -35 ft mlt along the seaward end of the north jetty toe and from -20 to -40 ft mlt along the seaward end of the south jetty toe. The authorized 38- by 300-ft channel has been maintained since 1957. Hudson's slope stability formula was used in the design with 10- to 35-ft wave heights. The design storm surge was +13 ft mlt. The stone sizes used were smaller than required to satisfy a no-damage criterion, with slope stability coefficients varying from 2.5 to 12.5 but being used for practical and economic reasons. The total cost of the repairs was $584,000 using a total of 60,600 tons of stone.
1967 1968	During September 1967, storm waves from Hurricane Beulah damaged the landward 1,130 ft of the 1965-1966 south jetty repairs. About 90 percent of this section of gulf side slope repairs had varying degrees of displaced stone. The damage appeared to be due to the placement of the stone against the concrete cap (a smooth impermeable section allowing very little natural interlocking of the cover layer combined with possible adverse changes in the magnitude and direction of wave forces). In 1968 this section and a portion of the jetty's channel side slope were repaired. On the gulf side, the concrete cap edge was broken off providing a buttress for the cover layer which was rebuilt by resetting existing cover stone and adding new filler, core, and cover stone. Also repaired were sections where undermining and cavities had formed beneath the concrete cap. In these areas the cap was broken up and overlaid with core and cover stone as was done for the 1965-1966 repairs. A 700-ft section of the south jetty (located approximately 3,700 ft from its seaward end) was repaired along its channel side by rearranging the existing cover stone and adding new filler, core, and cover stone. The south jetty repairs employed 0.5-to 4-in. filler stone, 200- to 1,000-lb core stone, and 6- to 8-ton cover stone. The north jetty shore protection was repaired by placing a 2-ft-thick bedding layer of 0.5-in. to 200-lb stone, 15-ft-wide cover layer of 6- to 8-ton stone, and 200- to 2,000-lb toe protection stone. The existing stone had moved up the shore slope during large storm events. Approximately 550 lin ft of shore protection were placed landward of the jetty. The total cost of the repairs was $274,000 using 14,100 tons of stone.

(Continued)

Table 12 (Continued)

Date(s)	Construction and Rehabilitation History
1971-1972	The seaward 290 ft of north jetty were rehabilitated (Figure 15). The design elevation and top width were +6 ft mlt and 16 ft, respectively. The design side slopes were 1V:2.5H on the inner 190 ft and 1V:3H on the head semicircle, with a 100-ft slope transition section between. The 16- to 18-ton cubical granite cover stone was placed in a double layer on the head semicircle and a single layer elsewhere. The remainder of the cross section employed 200- to 4,000-lb core stone. A 5-ft-thick blanket of 0.5-in. to 200-lb stone was placed beneath the toe of those sections where the new stone intersected the existing ground. The blanket extended from 10 to 20 ft beyond the toe of the cover layer. The design was based on Hudson's slope stability formula and a maximum wave height of 31 ft. The design surge level was +11 ft mlt. The computed slope stability coefficient varied from 11.9 to 14.3 (above the no-damage criteria). The design was chosen for economic reasons and the expected temporary nature of the repairs. A 1,000-ft jetty extension was in the planning stages. Total cost of the repair was $646,024 using 42,350 tons of stone. Hurricane Edith's passage in September 1971 temporarily halted completion of the repairs until the following year. (Storm waves damaged sections which exposed core stone.)
1977-1979	By the end of 1977, sections of the north jetty concrete cap had collapsed, other sections were cracking, and its seaward end needed repair. All of the noted areas of cap damage were located along the channel side. The damaged areas were similar to those seen previously on the south jetty cap where undermining and settlement of the underlying stone had created cavities beneath the cap. It was thought that Hurricane Anita in August 1977 was the force which triggered most of the cover stone breakage and collapse, because the jetty was considered to be in good condition during a June 1977 inspection. The north jetty channel shoreline was continuing to erode. Since 1962, the shoreline had receded about 200 ft, a rate of 13 ft per year. The channel end of the 1971 shoreline protection was now offshore. (The 1961 shore protection stone was virtually nonexistent.) During 1978-1979, repairs were made to the north jetty and adjacent shore protection. The seaward 35 ft and 1,700 ft of the jetty trunk were brought up to grade using 16- to 18-ton cover stone, 100- to 4,000-lb core stone (2,000-lb maximum on landward 1,000 ft of trunk), and 0.5-in. to 200-lb blanket stone. The trunk section (Figure 15), starting 500 ft from the seaward end and extending landward, had a 16-ft crown width, a +6 ft mlt crown elevation, and 1V:2.5H side slopes. The concrete cap was broken up, and the released cover stone projecting above +1 ft mlt was removed and used as cover stone in the shore protection (Figure 15). New core and a single layer of cover stone then were placed to obtain the required design geometry. A 3-ft-thick bedding layer was placed from

(Continued)

Table 12 (Concluded)

Date(s)	Construction and Rehabilitation History
1977-1979 (cont.)	the base of the existing jetty and extended 10 ft beyond the end of the new cover layer. The seaward end repair was identical to the 1971-1972 work, except that 1V:3H side slopes were used throughout. Displaced cover stone was reset on the adjacent 100 ft of jetty. The north jetty shore protection was extended 1,470 ft along the channel shoreline; this included 150 ft of the existing shore protection which was salvaged and rebuilt, and repairs were made to the existing section. The design was nearly identical to that used in 1968 on the existing shore protection. (Toe protection was 200 to 1,000 lb and placed with a top width of 5 ft.) The jetty design was based on Hudson's equation with a maximum wave height of 26.5 ft (trunk) and a maximum surge level of +10 ft mlt. Similar to previous improvements, the selected jetty design was chosen for economic and practical considerations in lieu of a "no damage" design. Total cost of the jetty repairs and shore protection was $5,905,000 using approximately 140,000 tons of stone.
1980	In August, storm waves from Hurricane Allen caused significant damage to the jetty heads and a section of the north jetty trunk had been breached. The breached section was about 50 ft long and located 350 ft from the head.
1984	There are several places along the jetties where the foundation has settled, resulting in the cover stone lying below mlt.

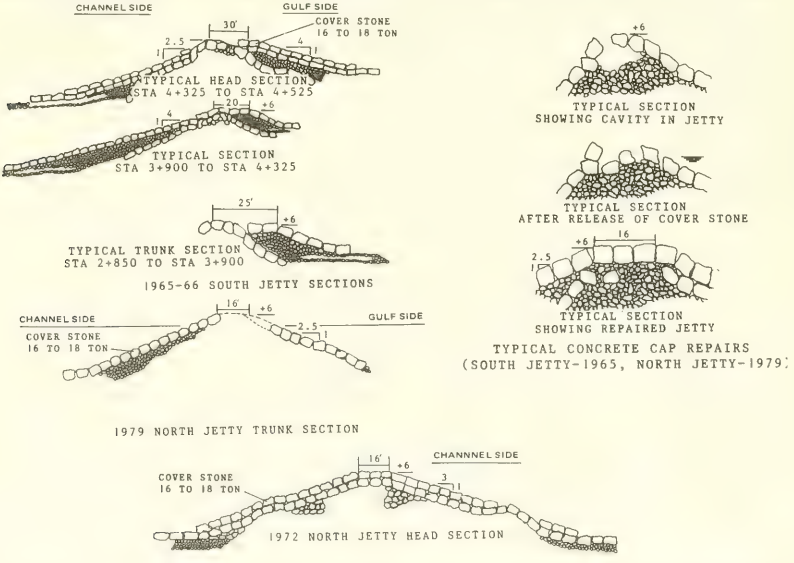

Figure 15. Typical repair sections of the Brazos Island jetties

REFERENCES

Kieslich, J. M. 1977. "Case History of Port Mansfield Channel, Texas," GITI Report No. 12, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Rhodes, H. J. and Simmons, H. B. 1966. "Matagorda Ship Channel Model Study, Matagorda Bay, Texas; Hydraulic Model Investigation," Technical Report 2-711, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Simmons, H. B., and Boland, R. A. 1969. "Model Study of Galveston Harbor Entrance, Texas; Hydraulic Model Investigation," Technical Report H-69-2, US Army Engineer Waterways Experiment Station, Vicksburg, MS.